# Oblig 1 FYS2160 2021

This oblig has two parts. The first part is a rather open problem where you are supposed to write in a report form. The report should be about 1000-2000 words plus sketches, figures and equations. The second part has detailed questions and relatively short answers.

We highly encourage you to get feedback on your report from a fellow student. Hand them your report without explaining and ask whether the intent abstract, methods, results and conclusion is clear to them as a reader. Would they be able to reproduce your results from reading your report?

## I. HEAT CAPACITY AND TEMPERFECT MUG

The Temperfect mug takes up heat from your hot beverage and releases it at a more pleasant temperature. In this oblig, we want you to (1) analyze data from an experiment run on the Temperfect Mug and identify its important features, then (2) modify a simple algorithmic model of heat conduction and (3) finally make an algorithmic model of the Temperfect mug.

We want you to cover these parts in a the form of a report with all the relevant sections. The order of the sections in the report do not have to follow the order things are presented here. We have made available guidelines to writing reports and an Overleaf template you may use. The final home examination will resemble this oblig in its form, and we will provide feedback on your oblig in line with our expectations for the final exam. In order to get a better grade you need to demonstrate through how you write the report that you have a broader and deeper understanding than just answering specific questions.

### A. The Temperfect mug experiment

FIG. 1: Experimental setup for comparing two steel thermal mugs, the Temperfect mug and a Bodum thermos mug

According to the producer, the Temperfect mug "extracts the excess heat from your freshly-brewed beverage to bring it to the perfect drinking temperature within minutes. That excess heat is stored in the wall of the mug, then used to keep your drink just right for hours."

We have measured the cooling of a beverage in a Temperfect mug. We would like to understand how the mug works and what features a model of the heat-storing material in the mug must have.

Two steel thermos mugs, the Temperfect mug and a Bodum thermos mug, were filled with 3 dl of almost boiling water. The lids were not put on to allow the temperature logging while the water in the mugs cooled. The air temperature $T_a$ outside the mugs was about 22 °C. Temperature of the water $T_w$ was logged in both mugs and the data stored in three columns in the file termokopper.txt: time in seconds and temperature in the two mugs in Centigrades.

We know that the main processes taking place in the two mugs are heat conduction and, in the Temperfect mug, energy storage in a phase change material. Use the cooling data to analyse these processes and model them. Here are some hints that may help you, but you should write the report as a self-contained text, not as answers to these hints and questions.

*a. Heat transport* In both the cups you may assume that when the water is cooled at the wall the water density increases and the water flows downwards creating a mixing flow in the cup. Due to this mixing flow you may assume that the temperature of the water is the same everywhere in the cup. Try to simplify the problem to become one-dimensional.

In the ordinary cup the temperature of the water changes due to heat flux $J_q$ to the surrounding air:

$$AJ_q = \frac{dQ}{dt} = mc_V \frac{dT}{dt}, \tag{1}$$

where $A$ is the area over which the heat transport is taking place and $Q$, $m$ and $c_V$ are the heat, mass and specific heat capacity of the water. Heat flux $J_q$ by heat conduction through a material (like the mug wall) is proportional to the temperature gradient

$$\vec{J_q} = -\lambda \nabla T, \tag{2}$$

where $T$ is the temperature and $\lambda$ the thermal conductivity of the material. You may assume that after a short while there is a stationary situation in the wall of the cup and you may replace the gradient operator by a ratio of differences, $\Delta T/\Delta x$.

Make a sketch of the heat loss from the ordinary (Bodum) mug by heat conduction. If you assume that the heat loss from the water is dominated by conduction through the walls of the mug you can show that

$$\frac{\Delta T}{\Delta T_0} = e^{-t/\tau}, \tag{3}$$

where $\Delta T = T_w - T_a$ is the difference between water and air temperature, subscript 0 indicates the initial state, $t$

is the time and $\tau$ is a time constant. From your sketch defining the problem and the above equations you should be able to find an expression for $\tau$ and from fitting the model equation 3 to the data you can estimate its value. Does the model describe the data for the ordinary mug well? Can you improve the model by assuming different rates of heat conduction through the walls of the mug and the top opening?

*b. Heat storage and release* As explained on the web pages of the Temperfect mug the walls of the mug contain a phase change material that melts or crystallises upon heating or cooling. The thermodynamic theory of phase changes will be introduced later, but in this exercise you will use the measured temperatures and one important fact about melting and freezing a crystal: "latent" heat must be added to a crystal to melt it and the same amount of heat is released when the liquid crystallises. Both melting and heating occurs at a specific temperature, the melting temperature $T_m$. Thus, while "latent" heat is supplied to an ice cube it melts, but does not change it's temperature.

Plot the temperature data for the Temperfect mug, analyse the curve and attempt to answer the following questions:

- What is the melting temperature $T_m$ of the phase change material in the Temperfect mug?
- During which period did the phase change material melt and during which period did it crystallise?
- How much heat was stored in the phase change material?
- How does the heat loss to the outside air of the Temperfect mug compare to that of the ordinary mug?

### B. Algorithmic models

Section 2.3 in the compendium and lecture 4 describe a microscopic algorithmic model of diffusion between two boxes with different concentration of particles. Since mass diffusion and heat conduction are governed by the same equation it is natural to try the same type of algorithmic model for heat conduction.

#### 1. *Heat conduction between metal blocks*

Figure 2 shows experimental heat conduction data together with the output from a simple algorithmic model, the Matlab code is given in the Appendix.

- Find values of the parameters `Ctb` and `tau` that give the best correspondence between the experiment and the model.

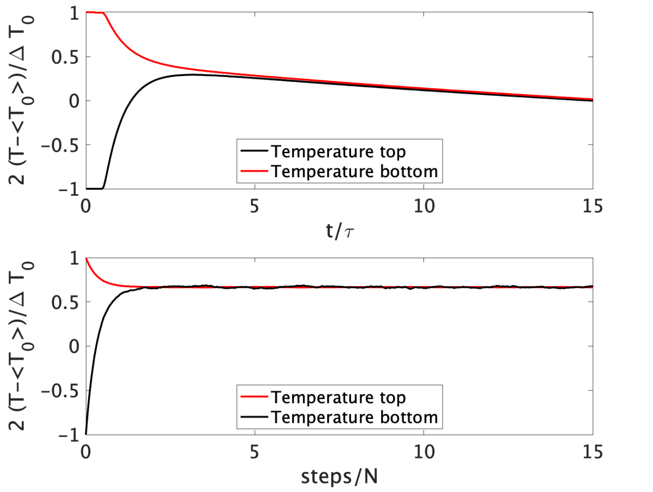


FIG. 2: **Heat conduction between two different metal blocks. Top:** Experimental data from exercise week 34 (performed during lecture 2) with rescaled temperature and time. **Bottom:** Algorithmic simulation using Matlab code in appendix.

- Which parameters are related to the thermal conductivity?
- Add one more component to the model (using a loop and random numbers) that represents the heat loss to the environment. What additional parameter do you have to add to achieve temperature data that resemble the experimental data?
- Describe the algorithmic heat conduction model and why it gives results corresponding to the experiments.

#### 2. *Modelling the Temperfect mug*

Can you make a similar algorithmic model of the Temperfect mug? How will you model the phase change material? Which parameters do you need to fit the model to the data?

## II. CONCEPT QUESTIONS

Please answer the following questions and justify your answers. Formulate your answers in short, precise language. This is as much a test of your ability to write as a test of your knowledge of thermal physics. Place the answers to these questions in an appendix of the above report.

1. A thermos bottle with a piston instead of a lid contains a fixed amount of gas. Because it is a thermos bottle, no heat can enter or leave the bottle. The piston is then pushed in, compressing the gas.

(a) Does the pressure of the gas increase, decrease, or stay the same?

(b) Does the temperature of the gas increase, decrease, or stay the same?

(c) Describe the behaviour of the molecules of gas during the compression and support your answers to (a) and (b) with an explanation in terms of their behaviour.

(d) Are there any other properties of the gas that change?

2. Consider the same system except now the bottle allows heat to go in or out of the bottle. The piston is moved slowly, and the temperature of the gas is maintained constant.

   (a) In terms of what is happening to the molecules, how is this situation different from the situation in the first question?

   (b) Does the pressure of the gas increase, decrease, or stay the same?

   (c) Support your answer to (b) with an explanation in terms of what is happening to the molecules of gas.

   (d) Are there any other properties of the gas that change?

3. A closed bottle contains water at the bottom and air above it in equilibrium at the same temperature.

   (a) Do the water molecules have more energy per molecule than the air molecules, less, or the same? Explain your answer.

   (b) Is the potential energy per molecule of the water molecules more negative than that of the air molecules, less, or the same? Explain your answer.

   (c) Do the water molecules have more kinetic energy per molecule than the air molecules, less, or the same? Explain your answer.

   (d) Explain how the water and air can be at the same temperature.

   (e) Explain what happens when the water and air are heated slowly so that they both continue to have the same temperature. Does the pressure change? What is happening to the molecules?

   (f) Now consider a glass of water filled with ice sitting on a table at room temperature. Describe what happens. Is the temperature of the ice the same as that of the water? What happens as the ice melts? Why does it melt?

## Appendix A: Algorithmic code

```
% Plotting font size
fontsize=20;
% Heat capacity ratio top to bottom
Ctb=5;
% Number of heat packets
N = 80000;
% Number of steps in simulation
nstep = 15*N;
% Time scale (characteristic time)
tau=N;
%Initialize temperature-time arrays
Tt = zeros(nstep,1);
Tb = zeros(nstep,1);
% Initial temperature top
Tt(1)=1;
% Initial temperature bottom
Tb(1)=-1;
% Room temperature
Tr=-1;

for i = 2:nstep
    r = 4*rand(1,1)-2; % Random number between 2 and
    DT=Tt(i-1)-Tb(i-1); % temperature difference top
    if (r<DT)
        Tt(i) = Tt(i-1) - 1/N; % Move heat quanta fro
        Tb(i) = Tb(i-1) + Ctb/N;
    else
        Tt(i) = Tt(i-1) + 1/N; % Move heat quanta fro
        Tb(i) = Tb(i-1) - Ctb/N;
    end
end
figure(1)
subplot(2,1,2)
plot((1:nstep)/tau,Tt,'r',(1:nstep)/tau,Tb,'k','LineW
xlabel('steps/N')
ylabel('2 (T-<T_0>)/\Delta T_0')
legend('Temperature top','Temperature bottom','Locati
ax2=gca;
ax2.FontSize=fontsize;
ax2.FontName='TimesRoman';
%%
D=load('metalblocks_lecture.asc','-ascii');
% Guessing the characteristic time
tau=100;
% Dimensionless time
t=D(:,1)/tau;
T1=D(:,2);
T2=D(:,3);
T10=mean(T1(70:90));
T20=mean(T2(70:90));
DT0=T20-T10;
Tmean0=(T20+T10)/2;
figure(1)
subplot(2,1,1)
% Plot rescaled temperature versus rescaled time
plot(t,2*(T1-Tmean0)/DT0,'k',t,2*(T2-Tmean0)/DT0,'r',
```

```
axis([0 15 -1.0 1.01])
xlabel('t/\tau')
ylabel('2 (T-<T_0>)/\Delta T_0')
legend('Temperature top','Temperature bottom','Location','South')
ax2=gca;
ax2.FontSize=fontsize;
ax2.FontName='TimesRoman';
```