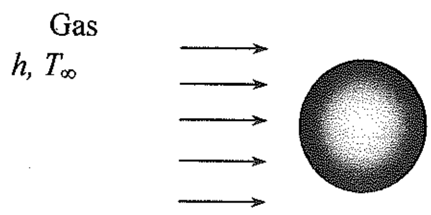
Support material permitted: attached collection of formulas.

Write on each and every page:
Code and name of the course
Name and student number
Department and date
Return this text together with your solutions

1.

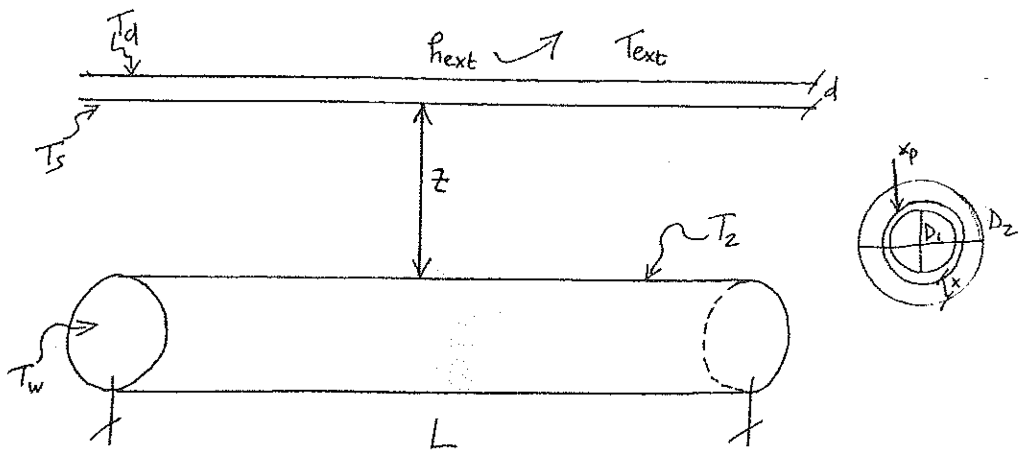
a) A small D=1.2mm metallic sphere is put inside a gas stream at some temperature T_∞:



i) Compute the Biot number if $k = 35W/mK$, $\rho = 8500\ Kg/m^3$, $c_p = 320\ J/kgK$. Explain the meaning of Bi and why it is crucial for this exercise.
ii) If $h = 65\ W/m^2K$, how long will it take to the sphere to reach 99% of the initial temperature difference $T_i - T_\infty$?

Hint: $L_c = D/6$ for a sphere of diameter D. The above implies that the ratio $(T(t) - T_\infty)/(T_i - T_\infty)$, i.e. the deviation of T from the initial difference, is very small...

b) It is planned to bury under a street an L=50m long stainless steel pipe ($x_p = 4cm$, thermal conductivity $k_p = 15\ W/mK$). The duct transports hot water at $T_w = 90°C$, and a layer of fiber glass insulation (x=5cm, $k = 0.038\ W/mK$) is wrapped around.



Assuming that the winter design temperature for the outside is $T_{ext} = -15°C$ and steady-state heat transfer occurs, find the minimum depth z so that the external surface of the pipe (at D_2) is at the freezing point. The heat loss at the ground level is $q'' = 20W/m^2$ on an area $A_{ext} = 50m^2$. The asfalt layer (with thickness d) has $k_d = 0.75\ W/mK$, while the soil over the pipe has thermal conductivity $k_s = 0.4\ W/mK$.

Problem data: x=5cm, $x_p = 4cm, D_1 = 50cm, d = 10cm,$
$k_p = 15\ W/mK,\ k = 0.038\ W/mK,\ A_{ext} = 50m^2,$
$k_d = 0.75\ W/mK, k_s = 0.4\ W/mK,\ h_{int} = 60\ W/m^2K, h_{ext} = 34\ W/m^2K.$

2.

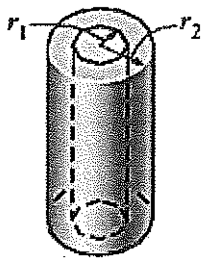
a) The floor of a patio is subject to dry wind, with average mean velocity $V_\infty = 7\ m/s$ and $T_\infty = 11°C$. The surface is at uniform temperature $T_s = 3°C$, and has dimensions $L = 12\ m$ and $W = 7\ m$.
The sky above the patio is approximately at temperature $T_{surr} = 10°C$. Compute the heat transferred in 10 mins due to radiation and convection (stationary conditions).

b) A double pane window of a storage room is H=0.8m high and W=0.8m wide. The air gap between the two panes is $\delta = 3cm$ wide, and it is filled with air at atmospheric pressure. The internal surfaces of the glass sheets are respectively at temperatures $T_1 = 4°C$ and $T_2 = 10°C$.
Calculate the heat transfer rate $\dot{Q}$ through the window only by convection.

3.

a) The blackbody radiation function f_λ: definition (with formula) and physical meaning, commenting on the defining formula. Definition of view factor and summation rule.

b) Two long concentric cylinders are at $T_1 = 300°C$ and $T_2 = 120°C$. The heat flux exchanged between the two surfaces is $q''_{12} = 3.21\ kW/m^2$. The emissivity of the external cylinder is ϵ_2=0.9 and r_1/r_2=0.4.
Compute the emissivity ϵ_1 of the internal cylinder.
Hint: vacuum is made between the two cylinders. Refer to the tables for the appropriate formulas.



c) A large new terrace for the front side of a turistic attraction, a castle, is being built during summer time. The floor (W=10m) and the castle wall (H=15m) can be modeled as perpendicular plates with a common edge.
In a (crude) first approximation, the surfaces are regarded as black body, and their length is assumed to be much larger than the terrace width. Compute the heat flux from the terrace to the wall, if $T_f = 42°C$ and $T_w = 32°C$.

4.

a) What is understood with the concept of condensation and condensation heat transfer? Give some example.

b)

The 6 m^2 external wall of a house consists of the following layers: gypsum, 9.5mm; mineral wool, 20cm; concrete, 10cm; bricks, 100mm. The room temperature is $T_i = 20°C$, the outer temperature is $T_o = 5°C$. The relative humidity is respectively $\phi_i = 60\%$ and $\phi_o = 85\%$. Compute the maximum amount of water vapour which will diffuse through the wall in 24 hrs.
Hint: the overall vapour resistance is analogous to thermal resistance.

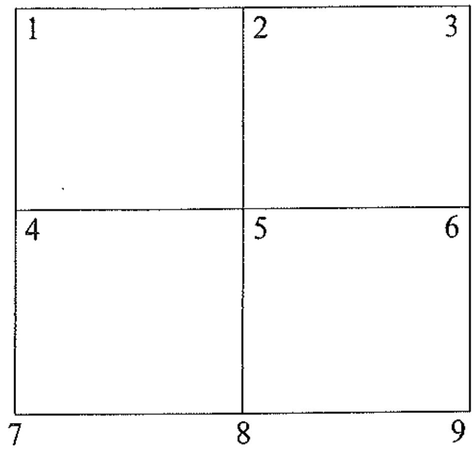
5.

Consider numerical methods for studies of heat transfer.

a) You are working on a computer-based numerical study of heat transfer for 12h inside a wall. After running the first simulation, you find that the temperature profile during the first hour deviates sensibly from the experimental data, but then it becomes quite consistent.
How do you explain this? How will you change your simulation parameters (time step and mesh) to increase the overall precision, especially during the first time steps?

b) A square 20cmx20cm plaquette has two sides at *constant* temperatures $T = 20°C$ (1-2-3 and 1-4-7), while the other two are subject to convection, with $h = 27.4\ W/m^2K$ and $T_\infty = 10°C$ (points 3-6-9 and 7-8-9). The thermal conductivity of the plaquette is $k = 3\ W/mK$.

By setting the nodal spacing $\Delta x = \Delta y = 10cm$, find the temperature at the middle point 5 (see the figure).



Hint: points 1, 2, 3, 4, 7 have a known constant temperature by construction. Exploit the symmetry of the system and use heat balance equations at points 5, 6, 8 and 9.