PHYSICS EXAM

1. Two bodies of water, each with a mass of 2.0 kg, are in thermal contact (and well insulated from the environment). At the moment, the temperatures of the bodies are 80°C and 20°C. The temperature of the hot water reduces at a rate of 0.00239 K/s at that moment. The energy flow because of heat transfer from the hot body is

   ❏ Zero
   ❏ – 0.143 K^2/s
   ❏ + 0.0116 W/K
   ❏ – 20 W
   ❏ – 10 W

   Explanation:...
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   ....
   ....
   ....

2. A fluid with a mass of 2.0 kg is evaporated in a well insulated container which is open at the top. The power of the electric heater is 200 W. Using a scale, it is determined that the mass of the fluid reduces at a rate of 0.133 g/s. The evaporation temperature is 120°C. Which of the values given below is correct?

   ❏ specific entropy of vaporization = 3.82 kJ/(K·kg)
   ❏ specific heat of vaporization = 0.75 MJ/kg
   ❏ specific entropy of vaporization = 1.91 kJ/(K·kg)
   ❏ specific entropy of vaporization = 12.5 kJ/(K·kg)

   Explanation:...
   ....
   ....
   ....
   ....

3. Air is compressed and cooled at the same time, in a reversible process. What process curve in the *T-S* diagram is *not* possible?

   ❏ horizontally to the left
   ❏ toward the top left
   ❏ toward the top right
   ❏ toward the bottom left

   Explanation:...
   ....
   ....
   ....
   ....

4. The shell of a house has an energy conductance of 300 W/K. Inside the temperature is 20°C, outside 0°C. How should the air inside be heated so that the inside temperature stays constant? With

   ❏ 6000 W/K
   ❏ 20.5 W/K
   ❏ 2050 W/K
   ❏ 8000 W
   ❏ 300 W

   Explanation:...
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   ....

5. The shell of a house (walls and windows) has an energy conductance of 300 W/K. The windows alone have an energy conductance of 80 W/K. Which statement is correct?

   ❏ The energy conductance of the walls alone is 109 W/K
   ❏ The thermal resistance of the walls is 220 W/K
   ❏ The thermal resistance of half the surface of the windows is 0.025 K/W
   ❏ The thermal resistance of the window surfaces is 0.025 K/W
   ❏ The thermal resistance of half of the window surfaces is 0.00625 K/W

   Explanation:...
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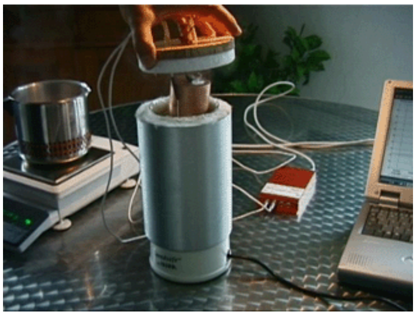
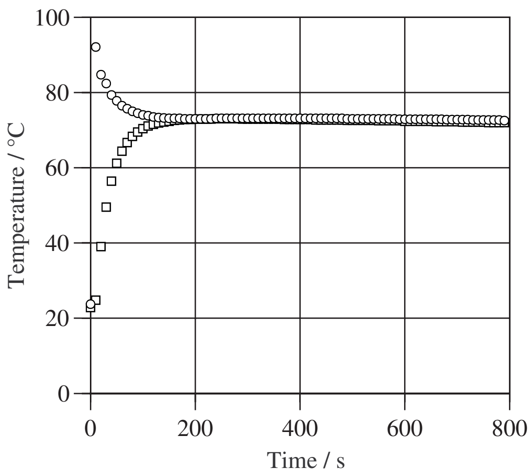
6. There is hot water in a thin walled aluminum can (top and bottom well insulated). A cold copper cylinder is put into the water which is constantly stirred a little.



   a. Sketch a system dynamics diagram with which the temperature of the water and the center of the copper body can be calculated. Sketch only the *energy balance* for all the important parts.
   b. Add the calculation for the water temperature to the sketch of your model. Explain (with words and formulas), how you obtain the temperature of the water.
   c. Add the calculation of the energy flow because of heat loss from the aluminum can. Explain (with words and formulas), how you calculate this energy flow.
   d. Sketch as carefully as you can the temperatures of the water and the center of the cylinder as functions of time. Explain important features of the result. Take the initial temperatures to be 90°C (water) and 20°C (copper). The outside temperature is 20°C.
   e. If the setup is put into a well insulated container, the following measurements result (see graphic). The masses of water and copper are 690 g and 2.760 kg, respectively. Determine the specific heat of copper.



7. In a perfectly insulated container there is 0.490 kg of a liquid. It is heated by an electric immersion heater and slowly stirred. In the table are the measured values (power of heating and temperature of the fluid) at various points in time.

   a. Determine the rate of change of the temperature at time 250 s.
   b. Determine the rate of entropy production as a function of time.
   c. Create the *T-s* (temperature - specific entropy) diagram of the liquid.
   d. What is the warming factor and the specific entropy capacitance at 290 K, 340 K, and 390 K?
   e. Determine the specific heat of the liquid as a function of the temperature (as a formula); in particular calculate the value of the specific heat at 290 K, 340 K, and 390 K.

Table 1: Heating of Fluid

Time / s	Power / W	T / °C
0	228	– 20.0
100	248	3.0
200	269	25.9
300	290	48.9
400	310	71.8
500	331	94.8
600	352	117.8

SOLUTIONS

1. Two bodies of water, each with a mass of 2.0 kg, are in thermal contact (and well insulated from the environment). At the moment, the temperatures of the bodies are 80°C and 20°C. The temperature of the hot water reduces at a rate of 0.00239 K/s at that moment. The energy flow because of heat transfer from the hot body is
   - ❑ Zero
   - ❑ – 0.143 K^2/s
   - ❑ + 0.0116 W/K
   - ✔ – 20 W
   - ❑ – 10 W

   Explanation: Balance of energy of hot body: dW/dt = IW. Capacitance law: dW/dt = C·dT/dt = m·c·dT/dt = 2.0·4180·(– 0.00239) W = – 20 W

2. A fluid with a mass of 2.0 kg is evaporated in a well insulated container which is open at the top. The power of the electric heater is 200 W. Using a scale, it is determined that the mass of the fluid reduces at a rate of 0.133 g/s. The evaporation temperature is 120°C. Which of the values given below is correct?
   - ✔ specific entropy of vaporization = 3.82 kJ/(K·kg)
   - ❑ specific heat of vaporization = 0.75 MJ/kg
   - ❑ specific entropy of vaporization = 1.91 kJ/(K·kg)
   - ❑ specific entropy of vaporization = 12.5 kJ/(K·kg)

   Explanation: dS/dt = λ·dm/dt, dS/dt = ΠS, ΠS = P/T. Therefore λ = P/T/(dm/dt) = 200 / (120 + 273) / 0.000133 J/(K·kg) = 3826 J/(K·kg)

3. Air is compressed and cooled at the same time, in a reversible process. What process curve in the *T-S* diagram is *not* possible?
   - ❑ horizontally to the left
   - ❑ toward the top left
   - ✔ toward the top right
   - ❑ toward the bottom left

   Explanation: Cooling means removing entropy. Reversible means no entropy productions. Therefore, the entropy of the gas must decrease, therefore, the process curve must go to the left.

4. The shell of a house has an energy conductance of 300 W/K. Inside the temperature is 20°C, outside 0°C. How should the air inside be heated so that the inside temperature stays constant? With
   - ❑ 6000 W/K
   - ✔ 20.5 W/K
   - ❑ 2050 W/K
   - ❑ 8000 W
   - ❑ 300 W

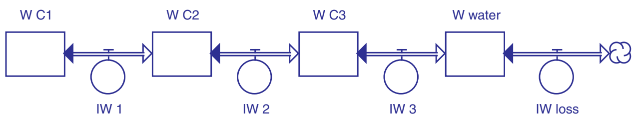
   Explanation: For the temperature to stay constant, the heating must equal the heat loss: IS_heating = IS_heat_loss. IS_heat_loss = G_S·(T – Ta) = G_W/T·(T – Ta) = 300/293·20 W/K = 20.5 W/K

5. The shell of a house (walls and windows) has an energy conductance of 300 W/K. The windows alone have an energy conductance of 80 W/K. Which statement is correct?
   - ❑ The energy conductance of the walls alone is 109 W/K
   - ❑ The thermal resistance of the walls is 220 W/K
   - ✔ The thermal resistance of half the surface of the windows is 0.025 K/W
   - ❑ The thermal resistance of the window surfaces is 0.025 K/W
   - ❑ The thermal resistance of half of the window surfaces is 0.00625 K/W

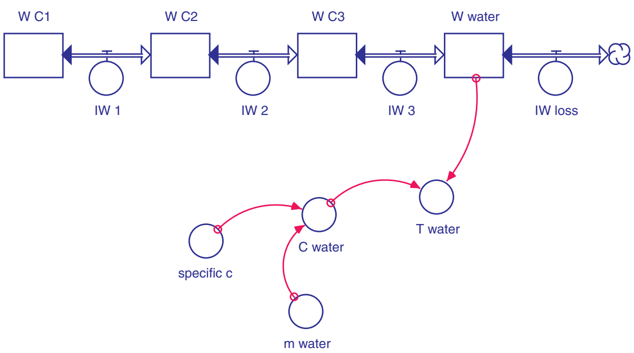
   Explanation: Conductances of parallel elements must be added. Therefore, half the windows have half the window conductance, i.e., 40 W/K. The corresponding thermal resistance is R_W = 1/G_W = 0.025 K/W.

6. There is hot water in a thin walled aluminum can (top and bottom well insulated). A cold copper cylinder is put into the water which is constantly stirred a little.

   a. Sketch a system dynamics diagram with which the temperature of the water and the center of the copper body can be calculated. Sketch only the *energy balance* for all the important parts.



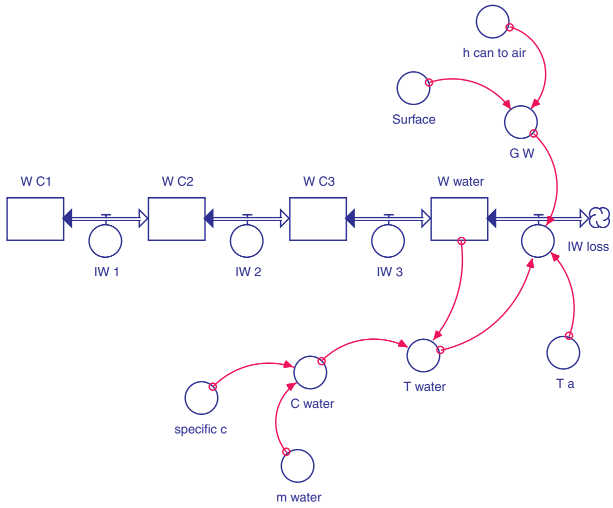
   b. Add the calculation for the water temperature to the sketch of your model. Explain (with words and formulas), how you obtain the temperature of the water.



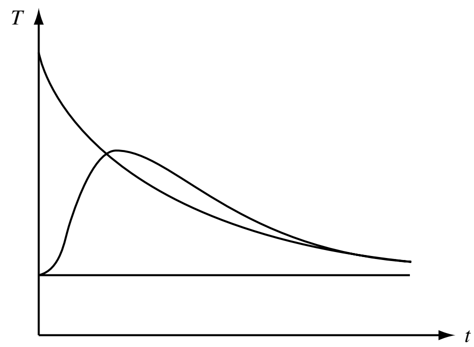
   Since the energy capacitance (mass·specific heat) of water is constant, we can calculate the temperature of the water easily from its energy: T = W_water / (m·c). Naturally, the initial value of the energy must be calculated correctly from W_water_init = m·c·T_water_init.

   c. Add the calculation of the energy flow because of heat loss from the aluminum can. Explain (with words and formulas), how you calculate this energy flow.

   The energy flow due to heat loss can be calculated with the help of the energy conductance G_W and the temperature difference: IW_loss = G_W · (T – Ta). The conductance is equal to the surface area of the mantle of the can (A), and the overall heat transfer coefficient (h) from the water to the air. This heat transfer coefficient is nearly equal to the heat transfer coefficient at the outside of the can since the can is very thin (and a good conductor), and the transfer from water to air also has a high heat transfer coefficient.

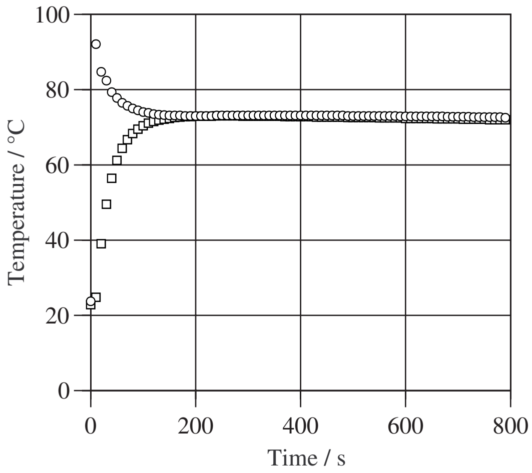


   d. Sketch as carefully as you can the temperatures of the water and the center of the cylinder as functions of time. Explain important features of the result. Take the initial temperatures to be 90°C (water) and 20°C (copper). The outside temperature is 20°C.



   Since the copper cylinder is a solid body, it will take time for heat to reach the center (there is a delay in the temperature function at the beginning). The temperature of the copper will be higher than the water temperature eventually (heat flows from copper to water to environment; the maximum is after the crossing of the temperature curves since the copper temperature is the one in the center). Because of stirring, the temperatures of copper and water will not go down to environmental temperature (after very long time, the temperatures of copper and water will become equal).

   e. If the setup is put into a well insulated container, the following measurements result (see graphic). The masses of water and copper are 690 g and 2.760 kg, respectively. Determine the specific heat of copper.



Balance of energy: ΔW_water = – ΔW_copper. m_w·c_w·(T_w_init – T_final) = – m_c·c_c·(T_c_init – T_final). Therefore:

$$c_{Cu} = -\frac{m_w c_w \left(T_{w,init} - T_{final}\right)}{m_{Cu}\left(T_{Cu,init} - T_{final}\right)}$$

$$= -\frac{0.690 \cdot 4180 \cdot (92-73)}{2.76(73-23)} \frac{\text{J}}{\text{K} \cdot \text{kg}} = 397 \frac{\text{J}}{\text{K} \cdot \text{kg}}$$

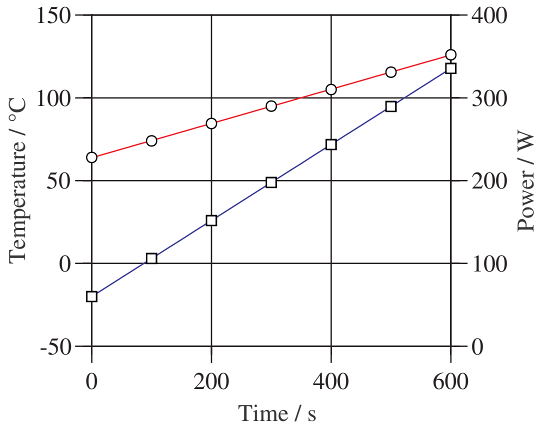
7. In a perfectly insulated container there is 0.490 kg of a liquid. It is heated by an electric immersion heater and slowly stirred. In the table are the measured values (power of heating and temperature of the fluid) at various points in time.

Table 2: Heating of Fluid

Time / s	Power / W	*T* / °C
0	228	– 20.0
100	248	3.0
200	269	25.9
300	290	48.9
400	310	71.8
500	331	94.8
600	352	117.8

a. Determine the rate of change of the temperature at time 250 s.

Rate of change of temperature is constant: dT/dt = 137.8/600 K/s = 0.23 K/s



b. Determine the rate of entropy production as a function of time.

Entropy production rate = dissipation rate / temperature of fluid (here it is constant!).

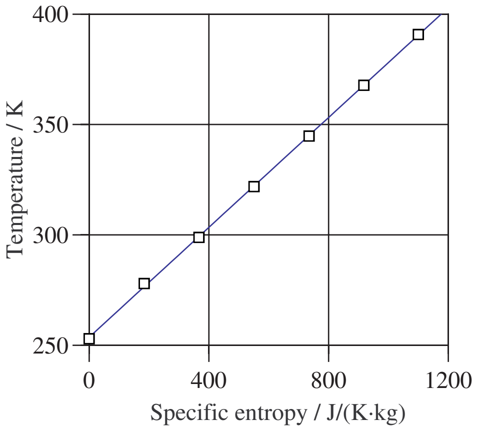
Table 3: Heating of Fluid

Time / s	Power / W	*T* / K	Π_S / W/K
0	228	253	0.90
100	248	278	0.89
200	269	298.9	0.90
300	290	321.9	0.90
400	310	344.8	0.90
500	331	367.8	0.90
600	352	390.8	0.90

c. Create the *T*-*s* (temperature - specific entropy) diagram of the liquid.

Table 4: Heating of Fluid

Time / s	Power / W	*T* / K	Π_S / W/K	s_{prod} / J/K·kg
0	228	253	0.90	0
100	248	278	0.89	184
200	269	298.9	0.90	367
300	290	321.9	0.90	551
400	310	344.8	0.90	735
500	331	367.8	0.90	918
600	352	390.8	0.90	1100



d. What is the warming factor and the specific entropy capacitance at 290 K, 340 K, and 390 K?

These quantities are constant since the Ts relation is linear:

Warming factor = slope of TS relation = 0.125 K^2kg/J
Specific entropy capacitance = inverse of warming factor = 8.0 J/(K^2kg)

e. Determine the specific heat of the liquid as a function of the temperature (as a formula); in particular calculate the value of the specific heat at 290 K, 340 K, and 390 K.

Specific heat = T·k_s (linear function with constant k_s).

c(290 K) = 2320 J/(K·kg)
c(340 K) = 2720 J/(K·kg)
c(390 K) = 3120 J/(K·kg)