

1. A system consists of a chamber and a 1 kg weight which can be at any elevation. The heat capacity of the system as a whole is 104 J/K. The surrounding consists of several thermal reservoirs, several weights, with weightless pulleys and strings which operate with negligible friction. The **initial state** is the weight kept at the top, and the system is at 300K. The **final state** is when system is the weight come down through a height of 1 m, and the internal energy of the system increased by the amount equal to loss in potential energy (temperature would have risen marginally = 9.81/104 K). Now study the following different processes:

Thermal reservoir

* 1. System goes (i) from state 1 to state 2 reversibly, and then (ii) back to state 1 reversibly (system is a closed system).
  2. System goes (i) from state 1 to state 2 irreversibly by free fall through 1m and then (ii) back to state 1.
  3. System goes (i) from state 1 to state 2 irreversibly but by connecting the weight to a 0.75kg weight in the surrounding, and then (ii) back to state 1 reversibly
  4. System goes (i) from state 1 to state 2 reversibly, and then (ii) back to state 1 irreversibly by the weight connected to 2 kg weight in the surrounding.

Compare this with Claussius inequality in two forms: and dS

In each case calculate, for both processes (i) and (ii), and for the entire cycle, ∫ δq/T, ΔSsys, and ΔSsur. ( For simplification assume all processes in the surrounding are reversible)

**SOLUTION:** Note that in all cases state 1 and state 2 are the same. (Please read the note put in moodle before looking at this solution)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| process | | ~ ∫ δq/T | ~ ΔSsys | ~ ΔSsur |
| a | i r | 9.81/300=0.0327 | 0.0327 | -0.0327 |
| ii r | -0.0327 | -0.0327 | 0.0327 |
| cycle | 0 | 0 | 0 |
| 1. When the weight is just lowered reversibly (and adiabatically), it raised a weight outside. The system’s internal energy remains constant since no mechanical energy is converted to internal energy in the system. Total energy decreases. However this is not the final state 2 that we are seeking. We need to raise the internal energy by 9.81 J (temperature by 0.000981 K), which can only be done reversibly by heat transfer from the surrounding.   Entropy changes ΔSsys and ΔSsur here are Q/T and –Q/T, since the entire process of going from 1 to 2 is reversible. The sum is zero.   1. This is just reverse of (i) 2. cycle is sum of (i) and (ii). Note that ΔSsys + ΔSsur here is zero, since the entire cycle is reversible. | | | | |
| b | i irr | 0 | 0.0327 | 0 |
| ii r | -0.0327 | -0.0327 | 0.0327 |
| cycle | -0.0327 | 0 | 0.0327 |
| 1. In the forward process, no work is done on the surrounding. The PE lost is entirely converted into internal energy raising the temperature. At the end of this, the system straightaway reaches state 2. No heat transfer is necessary. ΔSsys however remains the same as in a(i) since the end states are the same. ΔSsur is zero, since surrounding is left untouched. 2. Remains the same as in a(ii), since the same reversible process is adopted 3. Note that the cycle sum of for system plus surrounding is positive, since part of the cycle was irreversible. | | | | |
| c | i irr | 0.75x .0327=0.0245 | 0.0327 | -0.0245 |
| ii r | -0.0327 | -0.0327 | 0.0327 |
| cycle | -0.00818 | 0 | 0.00818 |
| 1. Only ¼ of the PE is converted into internal energy. Rest is used in raising the 0.75 kg weight in the surrounding. Hence you need to do 25 % less heat transfer than in a(i). ΔSsur = Q/T, since heat transfer has been done reversibly, and that is the only effect. 2. State 2 to 1 is reversible as in a (ii) and therefore all entries remain the same. 3. Note that ΔSsys + ΔSsur here is positive but smaller than in b (iii), since the irreversible degradation of mechanical energy to internal energy is less. | | | | |
| d | i r | 0.0327 | 0.0327 | -0.0327 |
| ii irr | - 0.0654 | -0.0327 | 0.0654 |
| cycle | -0.0327 | 0 | 0.0327 |
| 1. Same as in a(i) 2. Since now the weight will hit the top with some kinetic energy this will be converted to internal energy in the system (we have assumed that there are no irreversible effects in the surrounding). Hence the temperature would be 300K + 2 x 9.81/104 K. Hence the heat to be removed is twice that in the reversible process (a(ii)) | | | | |