ENV-413: Thermodynamics of the Earth systems

Exercise session for Lecture 4: Entropy and the 2nd Law

Reversible and irreversible processes

1. Circle the following if they are irreversible processes
a) Heat transfer through a finite temperature difference
b) Absorption of solar radiation
c) Expansion into a vacuum
d) Infinitesimally slow expansion against an opposing pressure

2. List two examples of irreversible processes in the atmosphere
   Precipitation, lightening

Entropy

1. Write the first law of thermodynamics, intensive, enthalpy form, expansion work.
   $c_p dT = dq + vdp \quad \Rightarrow \quad dq = c_p dT - vdp$

2. For the reversible expansion of an ideal gas, we may substitute for the specific volume from the equation of state. Make this substitution in #1. You should now have an equation that is a function only of q, T, and p, with dq on the left hand side.

$$pv = RT \quad \Rightarrow \quad v = \frac{RT}{p}$$

$$dq = c_p dT - \frac{RTdp}{p}$$

3. Divide both sides of the equation in #2 by T (you should get equation (2.23))

$$\frac{dq}{T} = c_p \frac{dT}{T} - \frac{Rdp}{p} = c_p d(\ln T) - Rd(\ln p)$$

4. With the term involving dq on the left hand side of the equation, the two terms on the right hand side of the equation are (exact, inexact) differentials
   exact

5. The sum of two exact differentials is (always, never, sometimes) an exact differential
   always

6. The some of two inexact differentials is (always, never, sometimes) an exact differential
   sometimes

It is important to remember that entropy is defined so that the change in entropy from one state to another is associated with a reversible process connecting the two states.

When a change in entropy between two given states occurs via an irreversible process, the change in entropy is exactly the same as for a reversible process: this is a consequence of entropy being a state variable and $d\eta$ an exact differential, which means that integration of $d\eta$ does not depend on the path (reversible or irreversible). Although the change in entropy is exactly the same for reversible and irreversible processes that have the same initial and final states, $\int dq/T$ is not the same for reversible and irreversible processes. To accomplish a given change in entropy (or state) by an irreversible process, more heat is required than when a reversible process is involved. This implies that reversible processes are more efficient than irreversible processes.

7. During a cyclic, reversible process, entropy (increases, decreases, remains the same)
   remains the same
8. Irreversibilities in a system cause entropy to (increase, decrease, remain the same)
   increase
9. A system undergoes a process between two fixed states first in a reversible manner and then in an irreversible manner. For which case is the entropy change of the system greater? Why?

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10. Is the value of the integral $\int_1^2 dq/T$ the same for all processes between states 1 and 2? Explain

11. Is the value of the integral $\int_1^2 dq/T$ the same for all reversible processes between states 1 and 2?

12. To determine the entropy change for an irreversible processes between states 1 and 2, should the integral $\int_1^2 dq/T$ be performed along the actual process path or an imaginary reversible path? Explain

13. How does the value of the integral $\int_1^2 dq/T$ compare for a reversible and irreversible process between the same end states?
    reversible > irreversible

14. Is it possible to create entropy? Is it possible to destroy it?
    Yes and No, entropy can only be created, never destroyed

15. Is it possible for the entropy change of a closed system to be zero during an irreversible process? Explain
    The fact that it is an irreversible process the total entropy must be > 0

15a. Entropy is an exact differential (true, false)

true

15b. If $\Delta\eta>0$, the process is (never, sometimes, always) irreversible

sometimes

15c.

$$\oint \left(\frac{dq}{T}\right)_{rev} = \eta$$

is true for (irreversible, reversible, both) processes

both

16. From the equation you derived in #3, write the expression for entropy change for an ideal gas in enthalpy form (you should get (2.26b))

$$\frac{dq}{T} = d\eta = c_p d(\ln T) - Rd(\ln p)$$

We now would like to derive the entropy change equation for an ideal gas in internal energy form. #17 - #19

17. Write the first law of thermodynamics, intensive, internal energy form, expansion work.

$$c_v dT = dq - pdv \Rightarrow dq = c_v dT + pdv$$

18. For the reversible expansion of an ideal gas, we may substitute for the pressure from the equation of state. Make this substitution in #17. You should now have an equation that is a function only of q, T, and v, with dq on the left-hand side.

$$dq = c_v dT + RT\frac{dv}{v}$$

19. From #18, write an expression for the entropy change of an ideal gas.

$$\frac{dq}{T} = d\eta = c_v\frac{dT}{T} + R\frac{dv}{v}$$

Use the expressions in #16 and #19 for entropy change to answer the following questions

23. Entropy will (increase, decrease, remain the same) in a cyclic reversible adiabatic process

remain the same

24. Entropy will (increase, decrease, remain the same) for isobaric cooling

decrease

25. Entropy will (increase, decrease, remain the same) for isothermal expansion

increase

27. Consider the isobaric heating of air from T=300K to T=400K. What is the entropy change for this process?

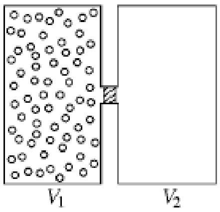
$$\int_{T_1}^{T_2} c_p d(\ln T) = c_p \ln(\frac{400}{300}) = c_p \ln(\frac{4}{3})$$

28. A hot potato cools by heat transfer to the cooler air.

a) Does entropy of the potato increase or decrease in this process? decrease

b) Does the entropy of the universe increase or decrease in this process? increase

29. Consider the system pictured below:



Gas is confined to a subvolume V_1 in an insulated rigid container. The container has an adjoining subvolume V_2, initially evacuated, which can be connected to V_1 by opening a valve ($V_1 = V_2$). Suppose the valve is opened and the gas flows out of V_1, filling the entire volume, $V_1 + V_2$.

a) The work done by the gas in this expansion is (positive, negative, zero). zero

b) The internal energy of the gas after the expansion (increases, decreases, remains the same). remains the same

c) The entropy of the gas after the expansion (increases, decreases, remains the same). increase

d) Is this process adiabatic? YES NO Yes

e) Is this process reversible? YES NO No

2nd Law of Thermodynamics

4. Heat can flow from a cold substance to a warmer substance
a) never
b) always
c) only if work is done on the system

5. Heat flowing from a cold substance to a warmer substance would violate
a) 1st law of thermodynamics
b) 2nd law of thermodynamics
c) neither the 1st or 2nd law

6. In a refrigerator, heat is transferred from a lower-temperature medium (the refrigerated space) to a higher-temperature one (the kitchen air). Is this a violation of the second law of thermodynamics? Explain

No, because work is done to extract the heat from the internal casing using energy from the environment. These combined make up the whole system.

7. Consider a person who organizes his room, and thus decreases the entropy of the room. Does this process violate the second law of thermodynamics?

No, room is not an isolated system

8. In a Carnot cycle, heat is transferred from a hot reservoir at T_2, partly converted to work, and partly discarded into a cold reservoir at T_1. The engine is returned to the initial state after one cycle. Sketch the Carnot cycle in the T-η plane on the diagram below, labelling T_1 and T_2, and the steps 1 through 4.

Step 1: isothermal expansion at T_2
Step 2: adiabatic expansion to T_1
Step 3: isothermal compression at T_1
Step 4: adiabatic compression back to T_2.