Problem Set 1

Thermodynamics and Climate Change

MOSTEC 2021

1. **Properties of a thermodynamic system:** If we take the top layer of the Pacific ocean as our thermodynamic system, which of the following are properties of that system? Which are not? Briefly state why.

   (a) Temperature of the water

   (b) Density of the water

   (c) The amount of water exchanged with lower layers each month

   (d) The concentration of dissolved oxygen in the water

   (e) The atmospheric pressure at the water's surface

   (f) Concentration of salt in the water

   (g) The amount of water that evaporates each day

2. **Concept questions:** Answer each with a brief but specific explanation.

   (a) For the following, state the type(s) and method of energy conversion (e.g. mechanical to thermal via frictional dissipation): (i) A block sliding down an incline and coming to a stop. (ii) Rain falling from a cloud and hitting the ground. (iii) The ground heating up in the sun. (iv) A forest fire. (v) Ice melting. (vi) Air expanding as it is heated.

   (b) For an ideal gas at constant pressure: (i) What happens to the volume when you increase its temperature? (ii) What happens to the volume if we remove half of the molecules of gas? (iii) Does heating the gas in this case require more or less energy to achieve the same temperature than if the gas was kept at constant volume instead?

(c) In which of the following cases is the First Law of Thermodynamics violated? Why or why not? (i) A solar sail in outer space that accelerates by sunlight shining on. (ii) A balloon that rises when you heat the gas inside. (iii) A block sliding on a frictional surface without slowing down. (iv) A device that extracts mechanical work from a heated block without cooling the block down. (v) The Moon causing tides on Earth.

(d) (i) Does ice absorb or release thermal energy as it melts? (ii) Does water absorb or release thermal energy as it evaporates?

3. **An Earth without its atmosphere:** The Earth's atmosphere is essential for maintaining its surface temperature above the freezing point of water.

   (a) Estimate the Earth's surface temperature if it had no atmosphere, modeling the system as a uniform rocky sphere exposed to sunlight in a vacuum. Assume that sphere is of uniform temperature. You can use the following average values for the Earth in your computations: solar irradiance at the upper atmosphere is about 1400 W/m^2, an average albedo (fraction of light that is reflected) of 0.3, and an emissivity of 0.8.

   (b) A more detailed computer simulation shows that Earth's surface temperature would be -18 °C without an atmosphere. Is your value higher or lower? Why might that be the case?

4. **Energy lost in a spring:** Let's say you have a linear spring with a spring constant of 750 N/m. This spring is non-ideal though and in fact dissipates some energy. You put in 5 J of work in compressing the spring such that its length changes by 10 cm.

   (a) How much work would it have taken if the spring was ideal and did not dissipate any energy?

   (b) How much thermal energy was generated in the process with the non-ideal spring?

(c) If the spring is made of iron and has a mass of 5 kg, by how much does its temperature change during this process? (Iron has a specific heat of capacity of 444 J/kg-K).

5. **(Challenge) Atmospheric pressure:** Derive the Earth's atmospheric pressure as a function of height above sea level assuming that it is an ideal gas for cases where:

   (a) The temperature profile is constant.

   (b) The temperature profile decreases linearly from 300 K at the surface to 200 K at the *mesopause*, 85 km above sea level.

   (c) How much work is done by a 1 kg packet of air rising from sea level to the mesopause (ignoring gravitational potential energy)? Assume that at all altitudes, the pressure of the air packet is equal to atmospheric pressure at that altitude. Use the equation you derived for the linear temperature profile case.

   (*Hint for parts (a) and (b): start with the ideal gas law and assume the pressure is hydrostatic - i.e. linearly proportional to height. Remember though that the density will be changing with altitude!*)

Resource: Thermodynamics and Climate Change
Peter Godart