Second Law and Gravity

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Apr 13, 2023
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"I am sure that the mistakes of that time will not be repeated;
we should probably make another set of mistakes."
— Winston Churchill

Introduction

Second law of thermodynamics dealing with heat and energy interexchange. A lot of textbooks mentioned that one simple statement of the first law is that heat always moves from hotter objects to colder objects (Wikipedia).

Such statement is not always correct, which will be demonstrated below.

Under Pressure

Let's take a look at the column of atmospheric air. The air is under the force of gravity. We all know that air pressure decreases with altitude. The molecules of air at the top and at the bottom of our column are not at the same condition.

The energy of air molecules inside thin bottom layer will be:

$$E = \sum \frac{1}{2} m v_i^2 \tag{1}$$

where m and v are mass and speed of the molecules.

Imagine that all these molecules moved to the upper layer of our column. According to the energy conservation law:

$$E = \sum \frac{1}{2} m u_i^2 + Nmgh = \sum \frac{1}{2} m v_i^2 \tag{2}$$

where g is standard gravity, h is the height of air column and N is the number of molecules.

The average molecule of the air is diatomic and:

$$\frac{1}{N} \sum \frac{1}{2} m v_i^2 = \frac{5}{2} k_B T_B \tag{3}$$

where T_B is the temperature at the bottom of the column. For the air temperature at the top we could write:

$$\frac{1}{N} \sum \frac{1}{2} m u_i^2 = \frac{5}{2} k_B T_T \tag{4}$$

Substituting (3) and (4) into (2):

$$\frac{5}{2}k_BT_T + mgh = \frac{5}{2}k_BT_B \tag{5}$$

So, the temperatures at the top and the bottom of air column will be different.

This makes perfect sense. When air molecules go up, its kinetic energy and thus temperature decreased according to energy conservation law. The molecules on its way down will gain kinetic energy and temperature.

The whole column of air is at equilibrium state and the heat does not necessary flow from hot to cold when potential energy exists in the system.

The Numbers

If we put all numbers into equation (5), then at 300K (25 ^{O}C) surface temperature, the equilibrium temperature at one-kilometer altitude will be 286K.

It follows that at temperature gradient of 13.7 degrees per kilometer there is no upward heat transfer in the atmosphere.

Temperature gradient measured in the Earth's atmosphere equals to 6.5 ^{O}C, which makes upward heat transfer in the atmosphere even less possible.