Homework 24

First law of thermodynamics.

During last physics club session, we start discussing heat. **Heat** (or **thermal energy**) is the energy transferred from one object to another due to their temperature difference. As we put two objects with different temperature in contact, in a certain time the temperatures of the objects will became very close to each other. Heat is transferred from the object with higher temperature to the object with the lower one. As it happens, the temperature of the first object is decreasing, and temperature of the second object is increasing, so the two temperatures approach each other. In a long time the temperatures will be almost equal and heat transfer almost completely stops.

So, heat transfer is one of the ways to change the objects temperature. As any energy, heat is measured in Joules (J). How much Joules we have to transfer to the object to change its temperature for 1 degree (please keep in mind that 1degree Celsius is equal to 1 degree Kelvin)? Firstly, this depends on the mass of the object. To heat up a bucket of water we have to spent more energy than that required to heat a glass of water – this is straightforward. Secondly, this energy depends on the material we are heating. Heating 1 kg of water for 1 degree will require more energy than this required to heat 1kg of dry wood for the same 1 degree.

It is convenient to introduce a specific quantity which depends only on the nature of the material and is equal to energy which is required to heat 1kg of a certain material for 1 degree. This quantity is called "specific heat". We will denote it as ***c***. Clearly, to heat a piece of the same material of mass ***m*** for ***ΔT*** degrees we need heat ***ΔQ*** which can be calculated as:

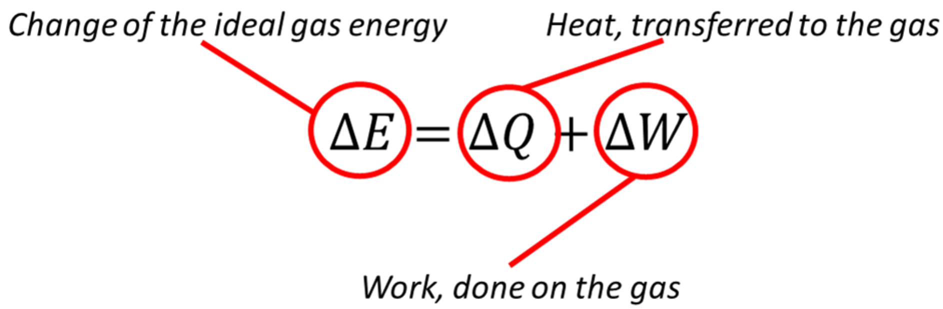
$$\Delta Q = m \cdot c \cdot \Delta T$$

Specific heat ***c*** is measured in $J/(kg \cdot {}^oK)$. Sometimes another unit of energy is used. This unit is called **calorie** (**cal**). By definition, this is the energy which is required to heat 1 g of water for 1^{o}C (to be exact, to heat 1g of water from 14.5 ^{o}C to15.5 ^{o}C). 1cal =4.186J

Temperature of the ideal gas also can be changed by the heat transfer.

Another way to change the temperature of the ideal gas is to do work on it. For example, during the recent class we saw that compressing gas at the constant pressure leads to increase of the gas temperature. We can see that both the heat transfer and the work can lead to the same result – increase in the gas temperature. So we can assume that heat is equivalent to work. Both heat and work are measured in Joules.

Ideal gas consists of moving particles. As long as the kinetic energy of the particles is proportional to the temperature, increasing the temperature means increasing the total energy of the ideal gas. (Please remember that the potential energy of the ideal gas particles is zero: they do not interact with each other – just colliding from time to time). We can write general expression for the change of energy of the ideal gas:



This expression is called "First law of thermodynamics". As we discussed, specific heat of the gas depends on heating conditions. These are two important particular cases.

For example, if the gas is being heated at a constant volume (the piston position is fixed), all the thermal energy supplied to the gas contributes to the gas heating. In this case we have "the specific heat at a constant volume C_V".

If the volume is constant, then the gas does no work. In this case, based of the first law of thermodynamics,

$$\Delta E = \Delta Q = m \cdot C_V \cdot \Delta T$$

If you know the temperature change and specific heat at a constant volume, you can calculate the change of the internal energy of the ideal gas in any process.

If during the heating the piston position is not fixed, the gas can expand and do work. The upper side of the piston is exposed to atmosphere, so the pressure is constant and equal to the atmospheric pressure. In this case, we need more thermal energy to heat the gas to the same temperature, because part of the energy supplied to the gas goes to work done by the gas. In this case we have "the specific heat at a constant pressure, C_P".

Problem:

1. A student eats a dinner rated at 1000 cal. She wishes to do an equivalent amount of work in the gym by lifting a 30kg mass to the height of 2m. How many lifts se has to do to spend all the energy? (Assume that no energy is spent when she drops the weight down).

2. 280 g of gas is being heated at a constant pressure. The amount of heat supplied to the gas is 600J. Specific heat at a constant pressure C_P = 745 J/kg^{o}K. Find the change of the gas's temperature.

3. 1kg of nitrogen expanded adiabatically and performed work of 300J. Find the change of the internal energy of the gas and the change of the gas temperature. C_V of nitrogen is 745 J/kg^{o}K. (Just to remind: "adiabatically" means that the gas was thermally isolated from the environment and ΔQ=0).

4. Gas with $m=1kg$, $p=2x10^5 N/m^2$ and $C_V=700$ J/kg°K was heated and expanded due to the heating. What is the specific heat of the gas in this process if its temperature increased by 2% and increase of its volume was $0.001m^3$ (We assume that the gas has high volume and temperature so its pressure can be considered as constant).

   Hint: To find heat capacitance c you should remember what it is. It was introduced as: $\Delta Q=cm\Delta T$. So if you find ΔQ and ΔT you can find c.