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2014 Problem 12: Cold Balloon

As inflated, a rubber balloon's surface becomes cooler to the touch

Abstract

It has been seen that when we release the gap of the air filled balloon, the air moves out and the balloon get cooler to the touch.

The problem is why the balloon gets cooler and what is the temperature of the each point of the balloon as a function of effective parameter?

Theoretically we will prove that the balloon and also the air inside will get cooler and we have gradient temperature on the surface of the balloon.

As you can see in this article finding the heat that moves from balloon to the air is easy, the real challenge is finding the temperature of the each point of the balloon. Due to this at first we make some assumptions and solve the problem using the assumption and then for making our model closer to the reality and what we seen in our experiments, we had tried to decrease our assumptions and we had been forced to use numerical solution to find the answer.

Introduction – Temperature decreasing

Due to the first law of the thermodynamic we have the relation between internal energy, heat and work for a thermodynamic system. When we push the air inside the balloon the air receive negative work then the internal energy will increase after that due to thermal

$$\Delta U = Q - W$$

equilibrium the temperature of the air will decrease until it reaches to the ambient temperature. Now we release the gap, the air moves out and it had done work. So the internal energy decreases again. And we reaches to a situation that the temperature is less than the ambient temperature.

This will occur during the time that the air moves out. So in this time the balloon's surface temperature is more than the air's, and we have a heat transfer from balloon to the air so the temperature of the balloon will decrease too. temperature drop at final.

Theory – Adiabatic process

First consider we have no heat transfer from balloon surface, we will fine the air energy in this situation and after that we add heat transfer to find the balloon's heat.

Because we have no heat transfer this process is adiabatic, we know in adiabatic process:

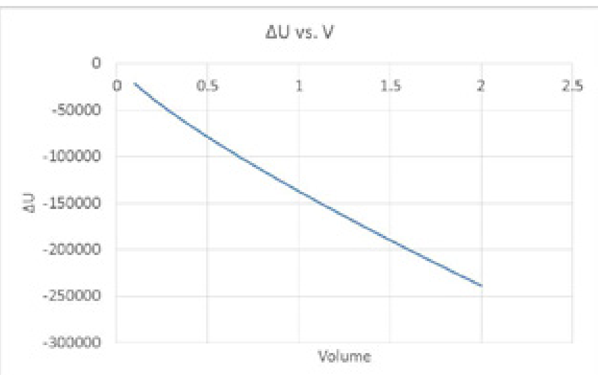
$$Q = 0 \qquad P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

To find the internal energy we only need to find the work of the air because we know that the heat is zero. We now calculate the work.

$$W = \int PdV \qquad W = \int_{V_1}^{V_2} P_1\left(\frac{V_1}{V}\right)^{\gamma} dV$$

$$W = P_1V_1^{\gamma}\,\frac{V_2^{1-\gamma} - V_1^{1-\gamma}}{1-\gamma}$$

The only thing left is to show the change of internal energy versus volume of the balloon.



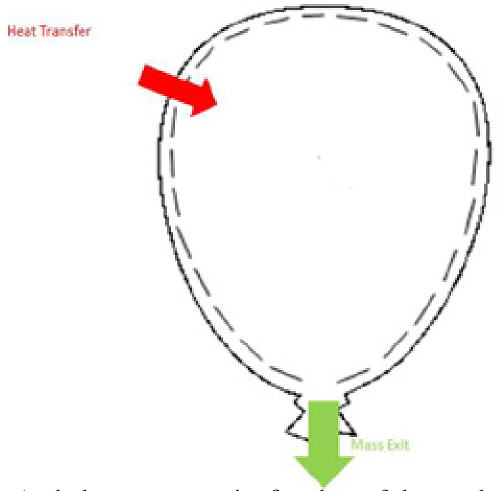
Here we consider the pressure inside the balloon is constant when we change the volume but we know that the pressure is a function of volume, the only way to find this function is to experiment it. And we had done it in the experiment part and you can see the correct chart there.

Heat transfer

We consider a control volume* inside the surface of the balloon. Now we know it has the outgoing mass transfer and heat transfer inside. We only need to find this heat. It's the heat transfer from balloon's surface to the air.

Here because we have only outgoing mass transfer we know it's a transient process, so we can write continuity equation for that. :

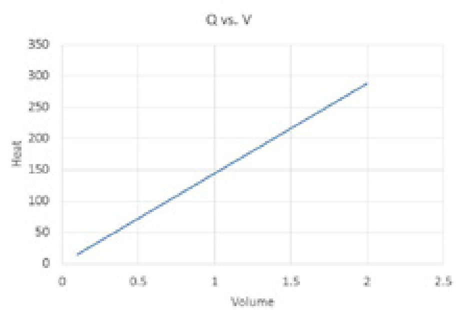
$$M_1 = M_e \qquad M_2 - M_1 = \sum M_i - \sum M_e$$



And also we can write first law of thermodynamic for control volume to find the heat transferred:

$$Q_{c.v.} = M\left(h_e + \frac{V_e^2}{2} - u_1\right) + W_{c.v.} \qquad E_2 - E_1 = {}_1Q_2 - {}_1W_2 + \sum M_ih_i - \sum M_eh_e$$

It's easy to understand heat as function of volume is linear, and the chart if like that:



Gradient temperature

At first we assume some assumption to simplify solutions and then we try to decrease them.

Assumptions:

1. Temperature of poles are constant
2. We only have conduction (no convection or radiation)
3. We had reached the heat equilibrium
4. The balloon has axis symmetry
5. Volume of the balloon is constant
6. We have no loss energy

We have basic equation for heat conduction transfer and we can conclude that the temperature for the end of the balloon is linear and has axis symmetry.

$$\frac{dq}{dt} = -k\frac{dT}{dx} \qquad T = C_1x + C_0$$

But it sounds awkward that it's linear so we try to decrease out assumption, we avoid this to assumptions:

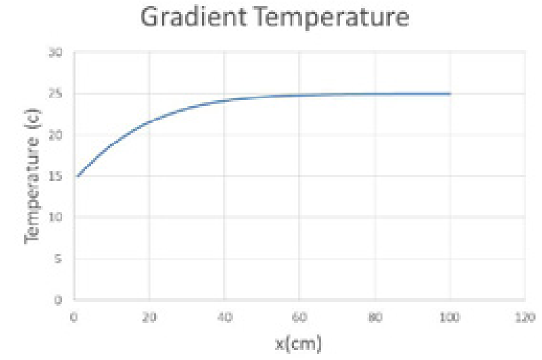
1. Temperature of poles are constant

2. We had reached the heat equilibrium

Know because we hadn't reach to thermal equilibrium we write the equation for each element of the balloons surface and solve them numerically.

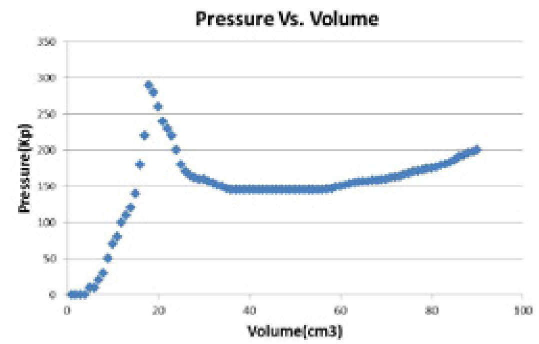
$$Q = \frac{kAt\Delta\theta}{L} \qquad \Delta Q(t) = \frac{kA\delta t\,(\theta_{x+1} - \theta_{x-1})}{L}$$

By numerical solution for this equation we can see the temperature versus position in the balloon.



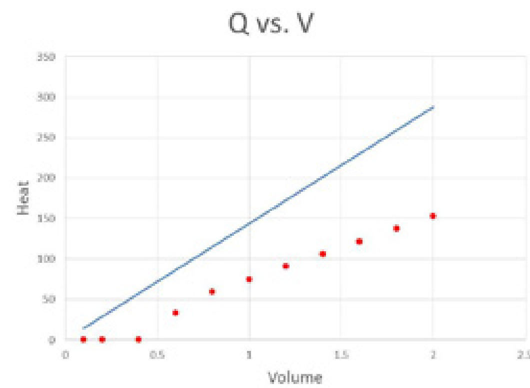
Experiments – P-V chart:

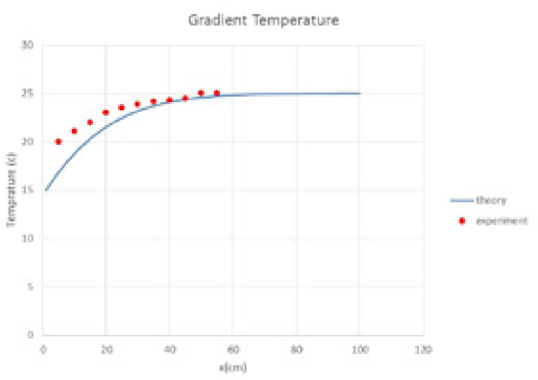
We have found the pressure as a function of volume using barometer. The real work of the balloon is the integration of this function.



Heat transfer

With infrared thermometer we are able to measure the each point of the balloon's temperature so we can find the heat that transferred from balloons' surface and also the temperature of each point.





Conclusion

We see that the air filled balloon, gets cooler when we release the gap and the air comes out. We explain this phenomenon with the first law of thermodynamic, and use control volume to find the heat transfer from the balloon's surface to the air, and plot it as a function of volume. Then we tried to find the temperature of the each point of the balloon. At first we assumed some assumption and found the answer awkward then we tried to decrease our assumption because of that we forced to solve equations numerically.

We experiment them too and we saw that the behavior of the charts are the same but we had a little different because of errors and air conduction.

Reference

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Abstract

A balloon becomes cooler when it changes the status from stretching to relaxation. The decreasing of temperature depends on the deformation of balloon. Here we performed two experiments to find the relationship between the temperature decreasing and the deformation of balloon. First, we stretched the balloon in one direction and measure the temperature decrease while the balloon was stretched to different length. Second, we blew the balloon and released, then measured the temperature decrease at deferent position of the balloon. The temperature decrease is correlated to a quadratic function of stretching length.

Keywords

balloon, stretch, temperature, cold

Introduction

As air escapes from an inflated rubber balloon, its surface becomes cooler to the touch. Investigate the parameters that affect this cooling. What is the temperature of various parts of the balloon as a function of relevant parameters?

A balloon is expanded to the limit when air is pumped into it. After the air goes out, the balloon relaxes, and we can observe that the balloon becomes cool. That is because the entropy of balloon structure increases and decreases when the balloon surface is getting tight or loose, respectively. There are some studies talking about thermal fluctuations and temperature rising with rubber elasticity, [1], [2] but no one discuss about temperature of balloon decrease when it is released. Here we focus on the relationship between stretching length and temperature decreasing. Furthermore, we also notice that the rate of stretching influenced on the range of temperature cooling.So we will discuss the connection between the rate of stretching and the temperature drop.