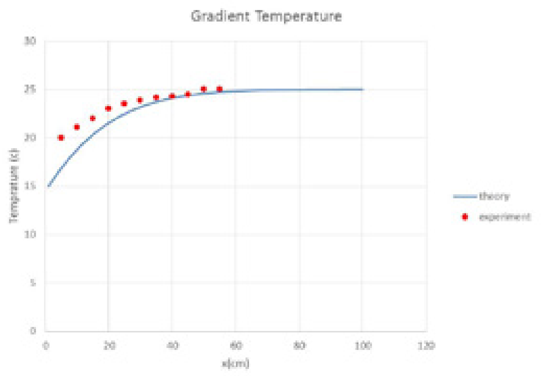

Conclusion

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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2014 Problem 12: Cold Balloon

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

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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.

Theory – entropy of a tight balloon in one dimension

In order to know what will happen when a balloon was stretched, we propose a simplified 1-dimensional model to simulate this phenomenon. We can imagine that a balloon is composed of a lot of long molecules. They are curly and folded generally, but when it is stretched by an external force, the folding will extend and total length will become longer than initial.

Fig. 1 is the proposed model which is based on the above conditions. The yellow rectangles are unit molecules. They connect to each other to form one dimensional piece of balloon. This is the reason why balloon has elasticity. The stretching force will change the folding condition of the molecules and thus the length of balloon increases. After the external force is released, the folding condition of molecules recovers, and thus the length also recover the original condition.

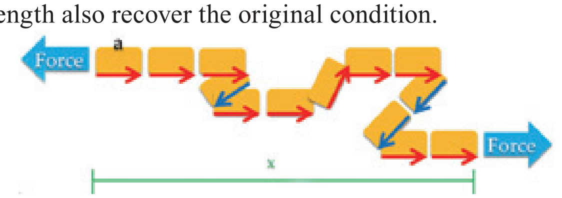

Fig. 1 the model of long molecule is a part of balloon.

Red arrow shows that the molecules are aligned backwards. Blue arrow which is backward means curly and fold. We suppose the length of each molecule is a, and N is the number of monomers, m is monomers forwards, and N-m is monomers backwards. So the total length x is:

$$x = ma - (N - m)a \quad (1)$$

so

$$m = \frac{1}{2}\left(\frac{x}{a} + N\right) \quad (2)$$

Since the entropy S=klnΩ, and Ω is the number of possibilities, we can write

$$\Omega = \frac{N!}{m!(N-m)!} \quad (3)$$

so

$$S = k\ln\frac{N!}{m!(N-m)!} \quad (4)$$

Thus from $\Delta T = \frac{-\Delta Q}{C_l}$ we can get

$$\Delta T = \frac{-T}{C_l}\int dS$$

Let l_0 = initial length and l = stretched length, we can solve the above equations and get:

$$\Delta T = \frac{kT}{2Na^2C_l}(l - l_0)^2$$

Experiment – Temperature decrease of balloon

We used a stepper motor to control the elongation of balloon, and attached a K-type thermal couple to the balloon for the measurement of temperature change. Fig.2 shows temperature of balloon increase and decrease with various kinds of stretching length. We can see that temperature increase with balloon stretching and decrease with balloon contracted. The length shown in the graph means how long the balloon is pulled then released. The temperature rose when balloon was stretched by motor synchronously. After getting to the length which was predestined, we kept equipment for few minutes to make balloon balance with room temperature, then we released balloon to observe the cooling effect of balloon. Fig.3, which was the enlarged of 90cm stretching, shows that the temperature of balloon increased and decreased in once stretching and contraction. Δt_1 was the time of stretching, and we can see that the temperature was increased. Δt_2 was the time of waiting the temperature of balloon balance with room temperature. Δt_3 was the time of contraction, and the decreasing of temperature was what we will discuss. Δt_4 was the time of waiting the temperature recovered to room temperature before staring the next step. Here we choose 40cm and 60~90 cm (Δl = 5 cm by step) to observe.

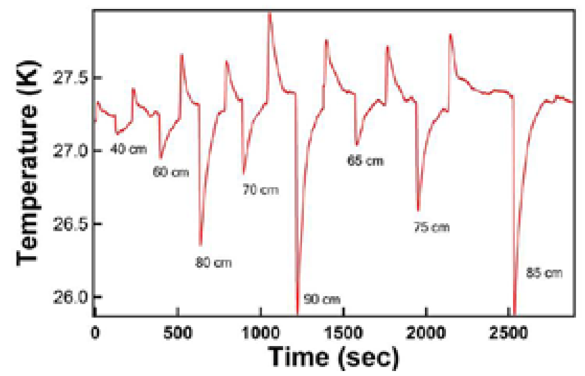

Fig.2 Temperature change with stretching and contraction.

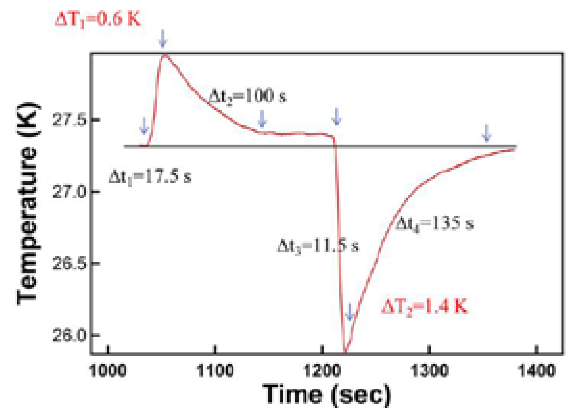

Fig.3 Temperature of balloon increased and decreased in once stretching and contraction.

As you can see in Fig.4, temperature change depended on the stretching length, and it directs to a quadratic curve. From 40~95cm, it is clearly increased with the longer stretching. Let us focus on the part of short stretching in the graph. When the elongation is about 40cm, the cooling effect is almost close to zero. It is because that the original length of balloon we used is 50cm. It seems that if stretching is not more than double of the original length, the cooling effect will not be obvious. But it is same at long stretching. When the stretching is getting to 85cm and 95cm, the changing amount of cooling effect don't follow the formula we show above.

We think that the reason of losing accurate at long stretching is because of the stretching rate, or like spring, which follow Hook's low in some stretching length. But if we put our view on the tendency of whole data, the result still show that the temperature decrease is correlated to a quadratic function of stretching length. We will talk about stretching rate later, but weather the cooling effect will miss in long distance or not is not the point in here.

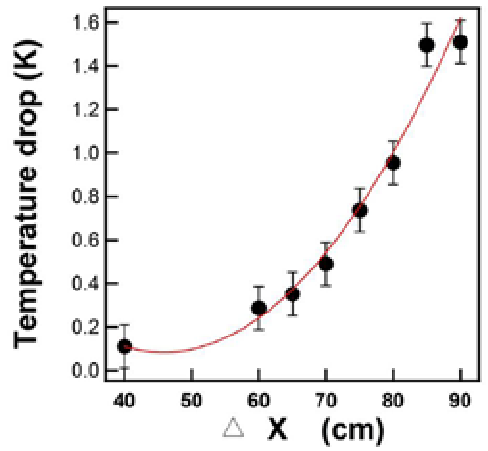

Fig.4 Temperature drop in different stretching length.

We also regulated stretching and release rate to test if the temperature cooling was stable in the stretching length and same rate. It can prove our experiment was stable and repeatable, because temperature cooling is the same over and over again in fixed rate. In addition, this phenomenon also can exclude that the temperature cooling effect miss at long stretching is made by artificial factor.

Fig.5 reveals that temperature cooling effect is influenced by different releasing rate. Here we choose three different rates to research. In order to make the temperature cooling difference much clearly, we used longer stretching length (65~105cm), which was longer than above we used. Fig.5 shows that the phenomenon of temperature cooling difference is not obvious when the stretching length are 65~85 cm, but it is clearly in 95~105 cm. At contraction was 65 cm, the temperature difference between three rate is about 0.2ºC. The phenomenon was unclear until the contraction is 85cm. However, when contraction length was 95cm, the temperature difference which contracted in 8.51 cm/s was 0.5ºC higher than the other two rate. This phenomenon is much clear when contraction length was 105cm. The temperature difference of slowest rate was 0.7ºC higher than the fast rate. Moreover, we can resolute that three contraction rates compare to three temperature difference. It is clearly that slower rate will have higher temperature difference. We believe that is because thermal transform from K-type thermal couple to balloon need some time. If contraction rate is too fast, the balloon will get more thermal from background instead of K-type thermal couple.

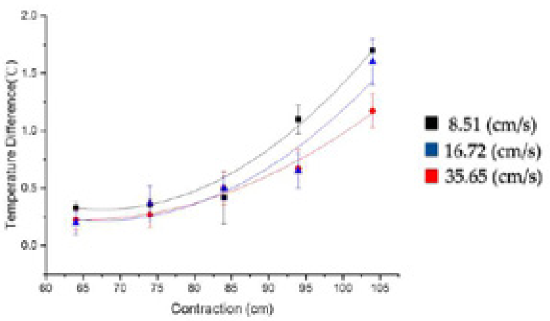

Fig.5 Temperature cooling effect measured with different contracted rate.

Conclusion

Our experiment shown that the temperature dropping caused by balloon contraction was increased with stretching length. Accurately, it was correlated to a quadratic function of stretching length. It may be misalignment when the stretching length was close to zero or too long. But it was precise at appropriate length. Moreover, we also made the research about temperature cooling effect with different contracted rate. The results show that when the rate was slower, the temperature cooling effect would be more obviously. It is important for future work about thermal transference with elastic material elastic material.

Reference

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