EXPERIMENTAL COMPETITION

17 January, 2011

Please read the instructions first:

1. The Experimental competition consists of one problem. This part of the competition lasts 3 hours.
2. Please only use the pen that is provided to you.
3. You can use your own non-programmable calculator for numerical calculations. If you don't have one, please ask for it from Olympiad organizers.
4. You are provided with ***Writing sheet and additional papers***. You can use the additional paper for drafts of your solutions but these papers will not be checked. Your final solutions which will be evaluated should be on the ***Writing sheets***. Please use as little text as possible. You should mostly use equations, numbers, figures and plots.
5. Use only the front side of ***Writing sheets*.** Write only inside the bordered area.
6. Fill the boxes at the top of each sheet of paper with your country (***Country*),** your student code (***Student Code***), the question number (***Question Number***), the progressive number of each sheet (***Page Number***), and the total number of ***Writing sheets*** (***Total Number of Pages***). If you use some blank ***Writing sheets*** for notes that you do not wish to be evaluated, put a large X across the entire sheet and do not include it in your numbering.
7. At the end of the exam, arrange all sheets for each problem in the following order:
    - Used ***Writing sheets*** in order;
    - The sheets you do not wish to be evaluated
    - Unused sheets and the printed question.

    Place the papers inside the envelope and leave everything on your desk. You are not allowed to take any paper or equipment out of the room

Deformation, Hysteresis, and Bistability

Instruments and equipment: rubber cord, wooden stand with the column, wooden ruler, 6 weights by 100 g each, measuring tape, thread, and pins.

Part 1. Stretching (4.5 points)

1.1 Fix the rubber cord to one side of the wooden column with the pins provided (Fig. 1). Measure the dependence of the cord length L on the gravity force of hanging weights. Carry out your measurements in two different ways:
loading process, i.e. increasing step-by-step the number of weights from 0 to 6;
unloading process, i.e. decreasing step-by-step the number of weights from 6 to 0.

1.2 Plot in the same graph the relative elongations of the rubber cord as a function of the gravity force of hanging weights at loading and unloading processes.

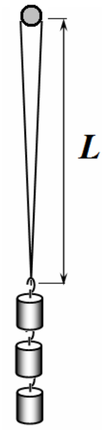


Fig. 1

Part 2. Equilibrium (7.5 points)

Place the ruler near the vertical wall of the column as shown in Fig. 2. Attach the rubber cord to the top of the ruler with the pins provided. Attach the other end of the cord to the column with the pins. The cord length l_0 in the unstrained state should be about 8 cm. The distance from the lower edge of the ruler to the top of the vertical column of the stand (see Fig. 2) is equal to the ruler length. Tie a thread to the top of the ruler so that the weights could be hanged on.

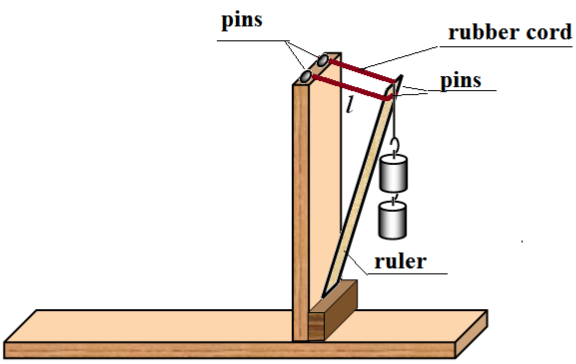


Fig. 2

Attention! *You will have to measure the length of the cord l with different number of hanging weights.*

Attaching the rubber cord, keep both sides to have the same length. For the sake of security wrap the rubber cord around the pins several times. Tie a knot at the end of the thread, attach it to the ruler upper side with the pins, and then put it over the upper edge of the ruler.

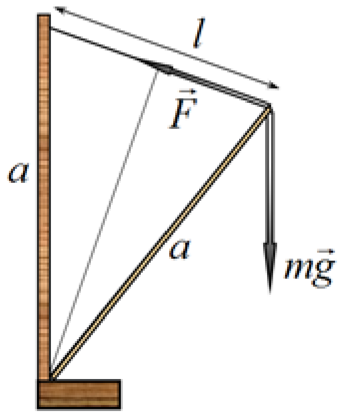
All measurements should be carried out very carefully: if you change the number of weights, hold the ruler by hand, then slowly move it downward or move upward until it comes into equilibrium, try to avoid oscillation of the weights. You can gently move the lower edge of the ruler horizontally along the column to find a more stable position of the ruler with the weights.

Theoretical description

2.1 Show that the condition of equilibrium of the ruler fixed as described above has the form:

$$F(l) = mg\frac{l}{a}, \qquad (1)$$

where l is the length of the cord, $F(l)$ denotes the elastic force of the cord at its length l, a stands for the length of the ruler, mg is the gravity force of hanging weights.



2.2 Using the data obtained in the first part of this experimental problem, plot in the same graph the dependences of the elastic force as a function of the length of the rubber cord at loading and unloading processes. **Please, do not forget that the initial length of the cord in this part of the experiment is different from that of the previous Part 1!** In the same graph, plot 6 graphs $f(l) = mg\frac{l}{a}$ for each of the six possible number of weights.

2.3 Using these plots find values of the cord length l corresponding to equilibrium positions at various number of weights in two cases: for the loading and for the unloading processes. Plot in the same graph the cord lengths in the equilibrium position against the gravity force of hanging weights for the loading (consecutive increase in the number of weights) and unloading processes (consecutive decrease in the number of weights).

Experiment

2.4 Conduct measurements of the dependence of the cord length l in the equilibrium as a function of the gravity force of hanging weights. Measurements are to be made in two ways, i.e. for loading and unloading processes.

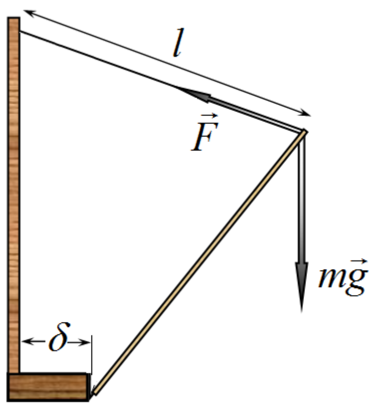
2.5 In the same plot you drawn in Section 2.3, plot the obtained experimental curves.

Part 3. Bistability (3 points)

If the lower edge of the ruler is shifted away from the vertical column (see Fig. 3), then at a certain length of the rubber cord and some number of weights it is possible to find two stable equilibrium positions of the ruler (bistability): the first one closer to the vertical, the second one closer to the horizon. In this Part you have to determine the conditions under which the bistability occurs.

We can show (but you do not need to do that!) that for the small displacement δ of the lower edge of the ruler, the equilibrium condition (1) is approximately described by the following formula:

$$F(l) = mg\frac{l-\delta}{a}. \qquad (2)$$



3.1 Plot schematically in the figure taken from section 2.3 such a function $f(l) = mg\frac{l-\delta}{a}$ that it represents the existence of two stable equilibrium positions and mark them on the figure. In the function $f(l)$ you can vary both parameters m and δ at your will.

3.2. **The length of the free part of the rubber cord should be the same as in Part 2.** Find experimentally two stable equilibrium positions of the ruler at the same number of weights. Find and write down at which number of weights those two stable positions really exist. Measure and write down the two lengths of the rubber cord at which these two equilibrium positions are achieved.

To search for the two equilibrium positions: a) put the ruler almost vertically and allow it to go down slightly holding by hand, b) stretch the cord until the ruler is almost in horizontal position and allow it to rise slowly holding gently by hand. Repeat these procedures several times!

When you try to find the bistability you are allowed to change slightly the free length of the rubber cord. If this length is changed, please, measure it and write down its new value (in cm).