SOLUTIONS FOR EXPERIMENTAL COMPETITION

Part 1

The measurement results are shown in Table 1. The last column gives the calculated values of the strain $\varepsilon = (l - l_0)/l_0$. The plot of the rubber cord length relative extension against the weights is shown in Fig. 1; 1 weight = 100 g.

Number of weights, N	L, cm	ε
0	20,8	0,00
1	23,1	0,11
2	28,1	0,35
3	37,2	0,79
4	49,7	1,39
5	61,3	1,95
6	71,2	2,42
5	65,2	2,13
4	55,3	1,66
3	42,1	1,02
2	31,5	0,51
1	24,6	0,18
0	20,8	0,00

Table 1

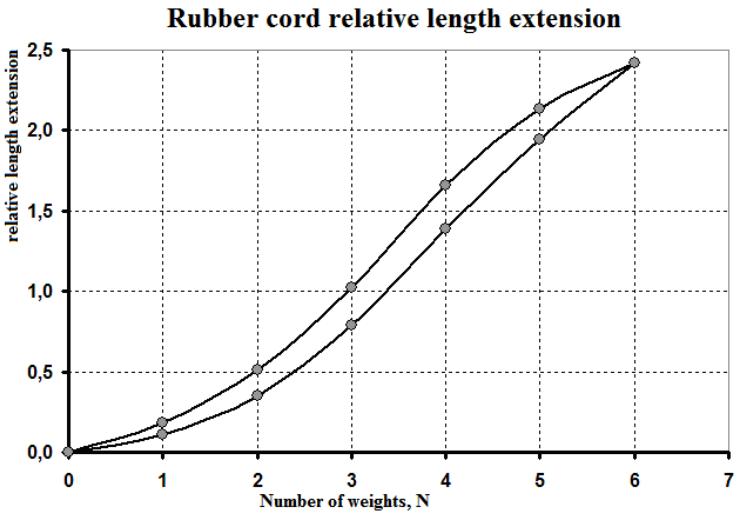


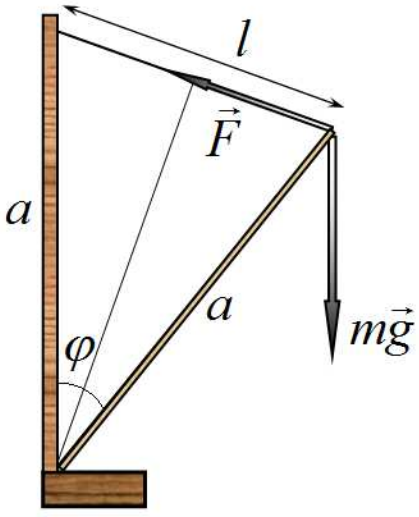
Figure 1

Part 2

2.1 The equilibrium condition follows from equating the torques of the elastic and the gravity forces written as

$$F(l)\,a\cos\frac{\varphi}{2} = mga\sin\varphi,$$

where φ is the angle of deviation from the vertical. Taking into account that $\sin\varphi = 2\sin\frac{\varphi}{2}\cos\frac{\varphi}{2}$ and $2a\sin\frac{\varphi}{2} = l$, we obtain the condition (1).



2.2 When plotting these graphs it is necessary to renormalize the length of the rubber cord for each value of the stretching force: $l = \frac{l_0}{L_0}L$. The curves of the functions $f(l) = mg\frac{l}{a}$ are straight lines passing through the origin. Required drawing is carried out in Fig. 2.

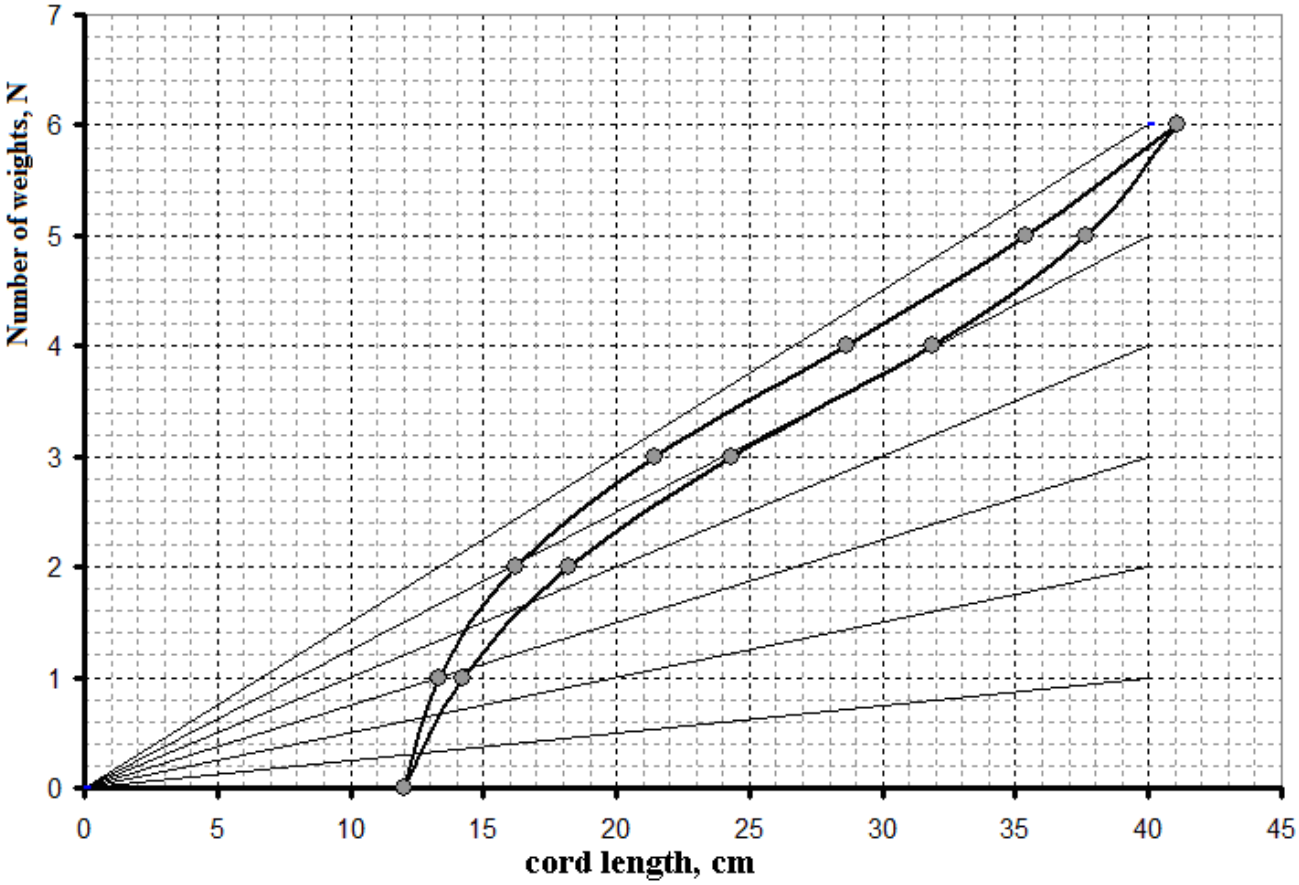


Figure 2

Equilibrium positions correspond to the intersection points of the graphs.

Table 2 represents the equilibrium positions found both with the help of Fig. 2 and obtained experimentally. Fig. 3 shows the corresponding curves, a fairly good agreement is achieved.

F, N	L, exp.	L, theory
0	11,6	12,0
1	11,7	12,5
2	12,0	12,7
3	13,1	13,2
4	14,6	14,0
5	18,4	16,5
6	51,0	47,0
5	48,7	40,0
4	18,2	17,0
3	14,6	14,0
2	13,0	13,5
1	11,8	12,5
0	11,6	12,0

Table 2

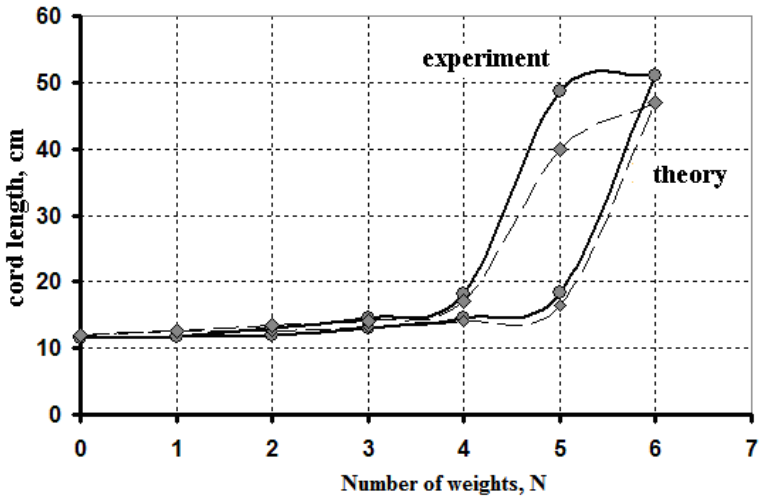


Figure 3

Part 3. Bistability.

The bistability is possible when the straight line $f(l) = mg\dfrac{l-\delta}{a}$ has three intersection points with the plot of the elastic force. A possible graph is shown in Fig. 4. Note that the intermediate position of equilibrium is unstable!

With the equipment provide the bistability is clearly observed at 5 or 6 weights (500 or 600 g).

The equilibrium positions correspond to the rubber cord lengths 13 - 14 cm and 36 - 44 cm.

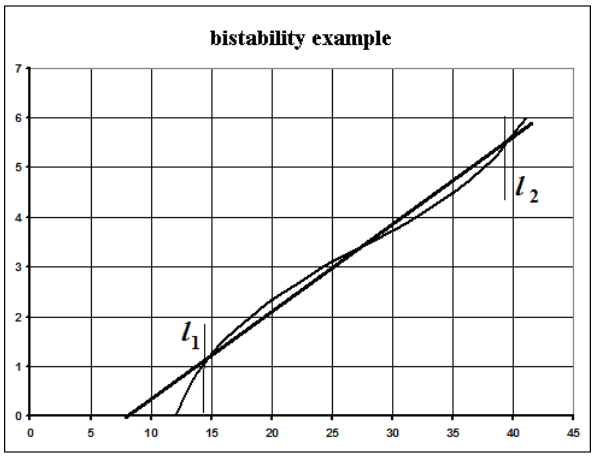


Figure 4

Marking scheme

	Content	Points
	Часть 1. Растяжение.	**4,5**
1.1	Measurements: - measurements made (12 points); - the hysteresis loop obtained; - measurement made with the accuracy less than 20% - measurement made with the accuracy less than 30%	 1 0,5 1,0 (0,5)
1.2	The plot of the unit elongation against the gravity of hanging weights: - calculation of the unit elongation for all experimental points; - the graph plotted (the axes are named and ticked; the points are placed according to the table; the approximate curve is drawn)	 1 1
	Part 2. Equilibrium	**7,5**
2.1	The proof for the equilibrium position: - the torque of the gravity force; the torque of the elastic force; - geometrical relations and trigonometric transformations;	 0,5 0,5
2.2	The theoretical calculation of the cord length: - fornula for calculation of the cord length from the unit elongation; - calculation for all values of the elastic force; - the graph of the elastic force against the cord length (the axes are named and ticked; the points are placed according to the table; the approximate curve is drawn); - 6 straight lines drawn;	 0,5 0,5 0,5 0,5
2.3	-the values are taken from the graph (12 points); - the theoretical curve of the cord length against the gravity force (he axes are named and ticked; the points are placed according to the table; the approximate curve is drawn);	0,5 0,5

2.4	Measurements: - measurements conducted (10 points); - the hysteresis loop is obtained (differences at 4 and 5 weights); - measurement conducted with the accuracy less than 20%; - measurement conducted with the accuracy less than *50%;*	 1 0,5 1,0 *(0,5)*
2.5	The experimental graph drawn: - the points are placed according to the table; - the approximate curve is drawn.	 0,5 0,5
	Part 3. Bistability	**3**
3.1	The qualitative explanation of the bistability: - the approximate curve of the gravity force against the cord length; - the shifted straight line is drawn to have three intersection points; - the stable equilibrium positions are determined;	 0,5 0,5 0,5
3.2	the stable equilibrium positions are found experimentally: - at the weight 500 g (or 600 g is possible); - the cord lengths at equilibrium positions are obtained in the intervals stated above	 1 0,5