10. Young's modulus of rubber

1) The setup is as follows. The rubber thread is fixed to the stand, and the plastic bag is fixed to the free end of the thread. The hex nuts are added, one-by-one, into the bag, starting with zero and ending with 15. The laser light is directed to the thread and the diffraction pattern is observed on the screen (which is a vertically fixed sheet of graphic paper on a support). The diffraction pattern from a wire is the same as from a single slit (the superposition of the Huygens sources from those two cases gives a full set of sources on a flat wave front, hence the electric fields from those two cases must provide equal and opposite wave amplitudes and equal intensities). So, if we measure on the screen the distance a between such maxima which are separated by n (e.g. $n = 10$) periods of the diffraction pattern then using small-angle-approximation, $n\lambda/d = a/L$, where L is the distance from the thread to the screen and d — the thread diameter. So,

$$d = nL\lambda/a.$$

The strain is calculated by making markings on the thread and measuring the distance b between these in a stretched state,

$$\varepsilon = \frac{b - b_0}{b_0},$$

where b_0 is the length in a non-strained state. The stress is calculated as

$$\sigma = \frac{4Nmg}{\pi d^2},$$

where N is the number of hex nuts in the bag and m — the mass of a single nut. The data are plotted in a graph; linear relationship corresponds to a straight line. The uncertainties are calculated using the rule of relative uncertainties, either using Pythagorean or simple addition, e.g.

$$\Delta\varepsilon = \varepsilon\,\Delta b\left(\frac{2}{b - b_0} + \frac{1}{b_0}\right),$$

where $\Delta b \approx 0.5\,\text{mm}$ is the length measurement uncertainty. Similarly,

$$\Delta\sigma = 2\sigma\,\frac{\Delta d}{d}.$$

These uncertainties are marked in the graph as error bars.

2) Using the plot, we need to determine such a value of $\varepsilon = \varepsilon_*$ that for $\varepsilon_1 > \varepsilon_*$, it is impossible to draw a straight line intersecting the error bars of all the data points with $\varepsilon_1 < \varepsilon_*$.