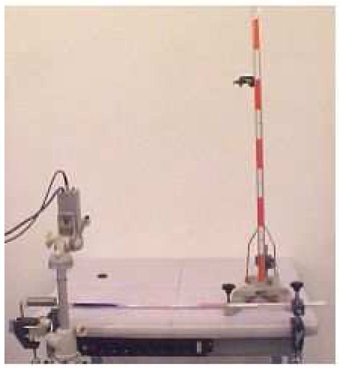
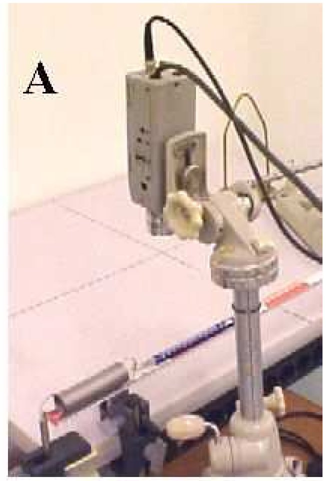
Hooke's law

Aim: This demonstration shows Hooke's law but also very much about measurements and how to interpret the results.

Subjects: 1A20 (Error and Accuracy)
1R10 (Hooke's Law)

Diagram:





Equipment:

- Spring (k=50N/m) with pre-stress (2.5N).
- Two rulers.
- Spring balance, 10N.
- Scale to be attached to spring balance (heavier than 250g).
- Mass: 200.0g.
- Video-camera.
- Beamer to project camera image.

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Presentation: One ruler is placed horizontal. The spring is fixed on it and can slide along the ruler when it is pulled by the spring balance (see DiagramA). The camera observes the position of the spring on the ruler and the force indicated by the spring balance, so all students can read the results obtained.

The second ruler stands vertical. The spring, with the scale fixed to it, hangs close to the ruler (see DiagramB). The camera observes again the position of the spring on the ruler.

We start with the horizontal arrangement. First, the equilibrium position (F=0) is read. Then the spring is given a displacement (x) of 5.0cm from its equilibrium. The corresponding force is read and the spring constant (k) is calculated: $k = \frac{F}{x}$. (We find: x=5.0cm; F=5.7N; so k=114N/m.) Also the error range (u) is determined: $\left(\frac{u(k)}{k}\right)^2 = \left(\frac{u(x)}{x}\right)^2 + \left(\frac{u(F)}{F}\right)^2$. (We find: u(x)=0.1cm; u(F)=.1N; so u(k)=3N/m.)

The spring is now fixed next to the vertical ruler and the scale is fixed to it. The camera is turned horizontal and observes again the position of the spring. First, the equilibrium position (h_o) is read. Then the mass of 200.0g is placed on the scale. The displacement of the spring (h_m) is read and the spring constant (k) is calculated: $k = \frac{mg}{|h_m - h_o|}$. (We find: h_o=35.6cm; h_m=38.8cm; using g=9.812415; so k=61.3N/m.) Also the error range (u) is determined: $\left(\frac{u(k)}{k}\right)^2 = \left(\frac{u(m)}{m}\right)^2 + \left(\frac{u(g)}{g}\right)^2 + \left(\frac{u(v)}{v}\right)^2$, in which u(v) is determined by $v = |h_o - h_m|$ and $u(v)^2 = u(h_o)^2 + u(h_m)^2$. (We find: u(m)=0.1g; $u(h_o)=u(h_m)$=0.1cm; u(g)=0.000001m/s^2; so u(k)=3N/m. Terms with m and g are neglectable in u(k).)

The two results are conflicting, because we see that the difference between the two calculated k-values is larger than two times the uncertainty in the error margin. The students are asked to discuss the possible cause of these conflicting results. After some time the word "pre-stress" appears in the student group.

Explanation: The spring is pre-stressed (F_p), so $k = \frac{F - F_p}{x}$. k is not proportional with F, there is only linearity between k and F. More measurements (F=f(x)) and making a graph will produce significant values. (We find F_p=2.66N with u(F)=0.08N and k=56.7N/m with u(k)=1.3N/m.)

Remarks:

- This demonstration is shown in our Introductory Laboratory Course.
- The first reading of x=5.0cm also has two error margins, so u(x) is actually higher ($u(x)^2$=0.02, and u(k)=5N/m).