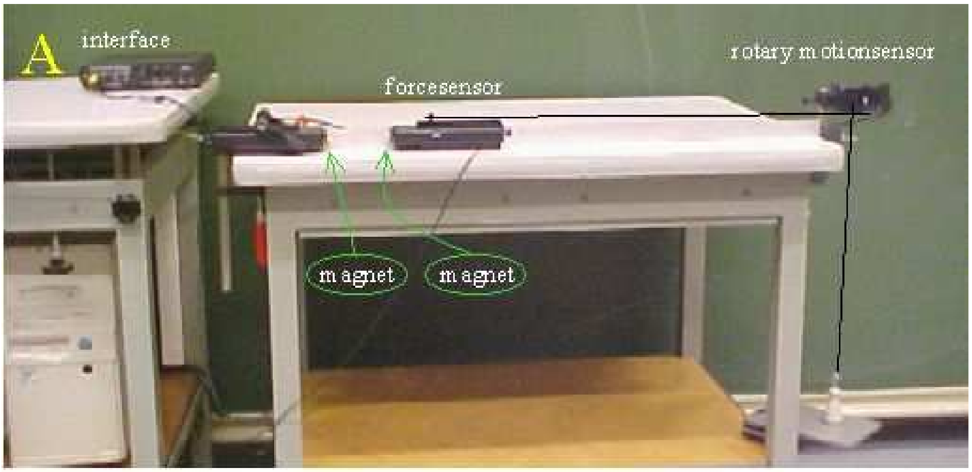
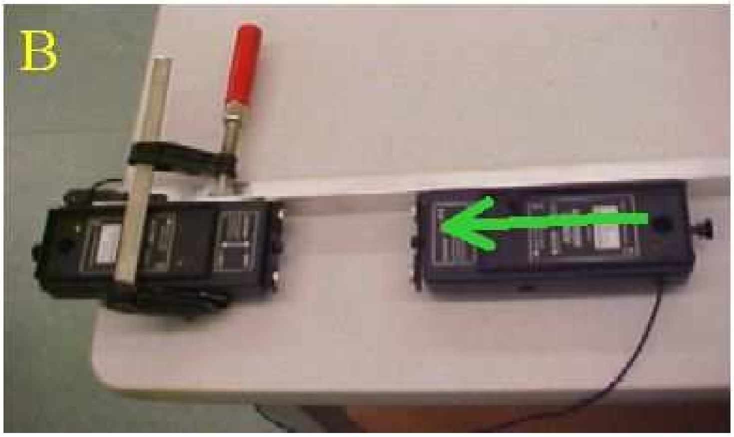
force between magnets (2)

Aim: To show how the force between two magnets depends on the distance between these magnets.

Subjects: 5H20 (Forces on Magnets)

Diagram:





Equipment:

- 2 Forcesensors.
- Magnets fixed to both forcesensors, opposing each other.
- Aluminum L-section to guide moving forcesensor.
- Rotary motion sensor.
- String.
- Mass, .2kg.
- Clamps.
- Data-acquisition system and software (we use Science Workshop).
- Beamer, to project monitorscreen to large group of students.

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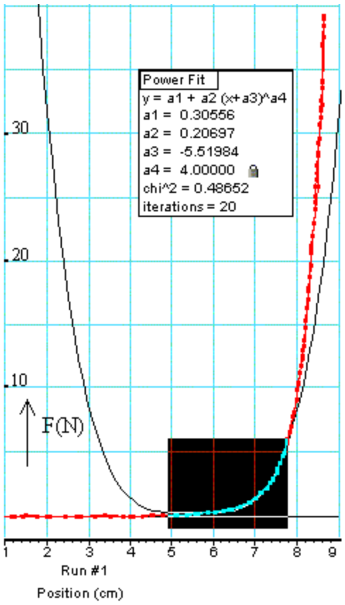
Presentation: The demonstration is set up as shown in DiagramA. One forcesensor is firmly clamped. Make sure the table stands firmly on the ground. We connect the moving forcesensor to the interface. The software is set in such a way that a graph of force versus displacement can be registered. Tare the moving forcesensor.

Start data-acquisition and, by hand, displace the free forcesensor quietly towards the clamped one. Take care to hold the moving forcesensor along the guiding section. A graph as shown in red in Figure1 will be registered.

Clearly can be seen that the force increases rapidly when the magnets approach each other. The curvefit-option in the software it is tried (powerfit). Choosing the region 5-7.8cm a powerfit with power 4 is a good option (see Figure1, the black line).



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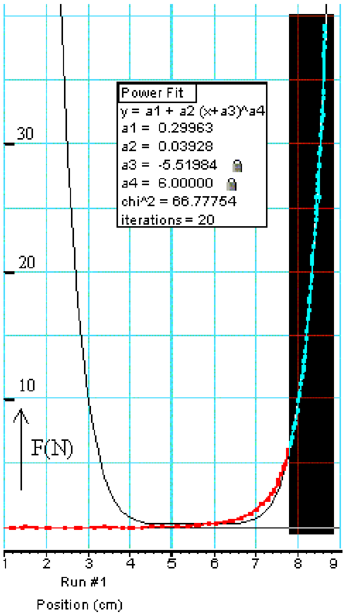
Power Fit
y = a1 + a2 (x+a3)^a4
a1 =  0.30556
a2 =  0.20697
a3 =  -5.51984
a4 =  4.00000
chi^2 = 0.48652
iterations = 20
```

Figure 1



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Power Fit
y = a1 + a2 (x+a3)^a4
a1 =  0.29963
a2 =  0.03928
a3 =  -5.51984
a4 =  6.00000
chi^2 = 66.77754
iterations = 20
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Figure 2

But it can be seen at the same time that for the region from 7.8cm to "touching magnets", the power in the formule needs a higher number. Selecting this region and applying a_3=-5.51984 (line of symmetry in the graph as found in the former selection) we find, by trial and error (trying to make chi^2 as low as possible), a power of 6 being more or less a good one (see Figure2).

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Explanation: The magnets that approach each other are dipoles. It are disc magnets, about 5mm thick. Such a magnet is a magnetic dipole. We analyse our demonstration by first looking at the magnetic field produced by one magnetic dipole and next look what will happen when a second dipole is placed in that field.

Many textbooks show that the magnetic field strength *(H)* of a dipole depends on the distance (*r*) as $H \propto r^{-3}$ (provided that $r \gg l$; (*2l* usually being the distance between the "poles").

When a second dipole is placed in such a field it experiences a net force, since the field is not uniform and the opposing forces on its North- and Southpole will not cancel. Figure3 can be used to explain this: If at P the magnetic field strength is H_x, then at Q, for a dipole of length *dx*, it will have the magnitude H_x+dH_x, or $H_x + \frac{dH_x}{dx}dx$.

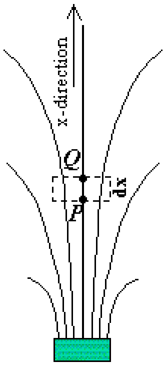

Figure 3

The forces on both poles are opposite:

$$F_p \propto H_x$$

$$F_Q \propto -\left(H_x + \frac{dH_x}{dx}dx\right)$$

The resultant force on dipole PQ:

$F_{dipole} \propto \frac{dH_x}{dx}$, so and applying $H \propto r^{-3}$ we get $F \propto r^{-4}$. The result of Figure1 verifies this.

When the magnets are very close, the expression $r \gg l$ is no longer valid (*l*=2.5mm) and the expression $H \propto r^{-3}$ for the field of the dipole will be different and so the expression for the force between the dipoles will be a different one.

Remarks:

- Quite some force is needed to push the opposing magnets towards each other. So clamp everything tightly otherwise the magnets might "shoot away" abruptly.

Sources:

- Duffin, W.J., Electricity and magnetism, pag. 153 and 78-83
- Mansfield, M and O'Sullivan, C., Understanding physics, pag. 484-486 and 441-443