# How About a Magnet and a Paper Clip? —

## *Experiencing the Interaction Forces Kinesthetically*

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Physics education research shows that many introductory physics students have difficulties fully grasping Newton's third law.[1] This is exacerbated when we ask for the validity of Newton's third law in areas outside of mechanics, such as electrostatics or magnetostatics. Undoubtedly, there is a difference between hearing about something and actually seeing or feeling it. Students can be told that two forces are equal and opposite but this by no means implies that they are convinced this is indeed the case. Some students respond with the correct answer but still harbor a remnant of doubt that the forces might not be the same.

In recent years, four different *TPT* articles have described some very nice illustrations that demonstrate Newton's third law using magnets.[2-5] It was my desire to go one step beyond a demonstration and to let the students *feel* the forces of action and reaction.

If two bar, rod, or disk magnets are held a short distance apart such that either the same or opposite poles face each other, my students have no problem agreeing that the two magnets repel or attract each other with exactly the same force. It is conceivable that we are receiving the correct answer here because students have had a chance to play with magnets in the past and had an opportunity to *feel* the forces of attraction or repulsion. Furthermore, due to the perfect symmetry in this situation, the response that both exert the same force on each other is the most obvious answer—after all, why should it be any other way?

However, if we replace one of the magnets with a stronger[6] or weaker magnet, opinions about the forces of interaction diverge, and the preferred answer ascribes a larger force to the "stronger" magnet.

**Fig. 1. An Alnico magnet and a piece of iron of the same mass are each indistinguishably encapsulated in nylon cylinders. Students can now simultaneously feel the force that the magnet exerts on the piece of iron and the force that the piece of iron exerts on the magnet.**

And what happens if we take this to the extreme, i.e., replacing the weaker of the magnets with a paper clip? Here, the situation is compounded by the fact that the magnet is perceived as the "active" agent and the paper clip is the passive partner. Many students argue that since the magnet attracts the paper clip the magnet exerts the larger force on the clip. What if students could simply *feel* the forces that the magnet and the paper clip exert on each other?

Here I would like to present a kinesthetic[7] demonstration that allows students to *feel* the interaction forces between a magnet and a piece of iron. Since a paper clip is typically much lighter than a magnet the

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Fig. 2. Three paper clips are imbedded in a nylon disk. The front of the disk is slightly sanded so that the three paper clips clearly show. The nylon disk can be attached to a force sensor to digitally record the force exerted on the paper clips.

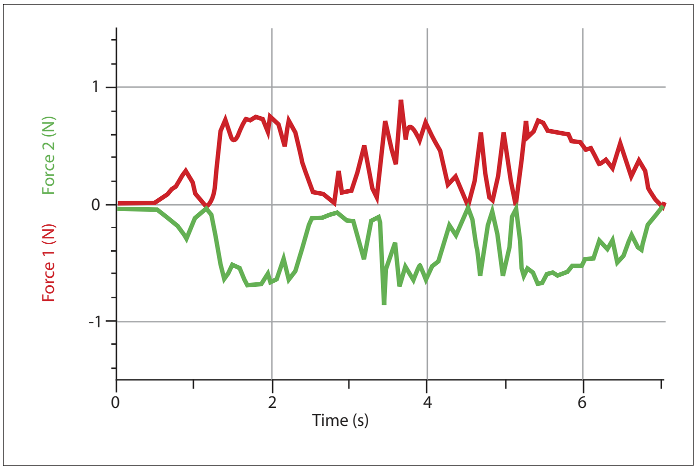


Fig. 4. Forces recorded simultaneously by both force sensors are displayed in one graph. One force sensor is set to read pull as positive; the other force sensor is set to read pull as negative.

Fig. 3. Three paper clips, imbedded in a nylon cylinder, as shown in Fig. 2 are mounted on one force probe. A second force probe holds a nylon cylinder of the same dimension that contains a small neodymium magnet. For convenience sake we have mounted the force sensors on dynamics carts.

discrepancy in perceived weight distracts from our goal—to feel the magnetic forces between the two. To eliminate this distraction, we replace the paper clip with a piece of iron having the same mass as the magnet. We use an Alnico ring magnet with a thickness of 1.7 cm, an o.d. of 7 cm, and a bore of 3 cm (Fig. 1). Both the magnet and the piece of iron are indistinguishably imbedded in a piece of nylon. A handle prevents fingers from being pinched between the magnet and the piece of iron. I typically do not tell the student, who is about to find out for himself/herself which of the two objects exerts the larger force on the other, if the magnet is contained in the right or the left nylon cylinder. When students cannot tell which one exerts the larger force on the other, I often suggest that they might want to switch sides and hold the left object in the right hand and vice versa. And if students still cannot determine which object exerts the larger force, then the obvious conclusion is that both exert the same force on each other.

While I regard this kinesthetic experience as a quintessential element in the learning process, it is only a first step and does not provide a quantitative result. To this end, I follow up the kinesthetic experience with a quantitative experiment that allows students to measure both forces and to display them graphically. For this purpose we have epoxied a neodymium magnet in one, and three paper clips in another small nylon cylinder as shown in Fig. 2. The nylon cylinders can be attached to a force sensor. To move the magnet and paper clips conveniently toward or away from each other, we mount the force sensors on dynamics carts as shown in Fig. 3.

By displaying the force read by both force sensors simultaneously (cf. Fig. 4), students obtain a pictorial confirmation of Newton's third law on a moment-by-moment basis. The pictorial representation helps students to better remember this experience.

Several extensions complement the set of experiences for this student activity:

1. A nylon cylinder containing a large magnet and another nylon cylinder containing a small magnet can both be attached to two force sensors as described above. Since the two nylon cylinders are indistinguishable, I challenge my students to determine which cylinder contains the stronger magnet.
2. The combination of a larger piece (3.5-cm diameter) of iron and a small magnet mimics the situation we find when we look at refrigerator magnets. Again I ask my students whether the refrigerator magnet exerts a larger force on the refrigerator, whether the refrigerator exerts a larger force on the magnet, or whether they possibly exert the same force on each other.
3. Finally, consider a set of nylon cylinders containing two neodymium magnets with the same poles facing each other. Students use this combination to confirm Newton's third law in repulsion.

The combination of the kinesthetic experience with the quantitative experiments described here bring introductory physics students closer to a grasp of Newton's third law.


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## References


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2. Eric Gettrust, "An extraordinary demonstration of Newton's third law," *Phys. Teach.* **39**, 392–393 (Oct. 2001).
3. Howard Brand, "Action-reaction at a distance," *Phys. Teach.* **40**, 136–137 (March 2002).
4. William Lonc, "Novel third-law demonstration," *Phys. Teach.* **33**, 84 (Feb. 1995).
5. Robert Chasnov and Louis Overcast, "Magnet symmetry and Newton's third law," *Phys. Teach.* **28**, 112 (Feb. 1990).
6. In an initial encounter with magnets, we can let students define the strength of a magnet by the number of paper clips the magnet can pick up at one time.
7. The word *kinesthesia* comes from the Greek words *kinein* (to move, to set in motion) and *esthesis* (the experience). A kinesthetic experience is the experience of motion or the sensation of movement and the forces we feel in our muscles, tendons, and joints. Most are familiar with the word *anesthesia,* which literally amounts to having no experience.



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