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# An Easy-to-Use Magnetic Dynamometer for Teaching Newton's Third Law

**Fitria Silviana[1] & Soni Prayogi[2]**
[1]Department of Physics Education, Medan State University, Indonesia
[2]Department of Electrical Engineering, Pertamina University, Indonesia
*Corresponding Author: soni.prayogi@universitaspertamina.ac.id

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***Abstract*** *- The study of Newtonian mechanics gives students the first chance to question their commonsense assumptions and replace them with a more comprehensive worldview. Newtonian mechanics is a cornerstone of contemporary science. Furthermore, despite its essential significance, multiple studies demonstrate how challenging it is to properly comprehend the key elements of Newton's equations. Any initiatives to increase their teaching options are therefore encouraged. In order to help instructors in particular applications of Newton's third rule of action-reaction, we provide an experimental instrument. Our method consists of two flexible plastic strip dynamometers that have miniature neodymium magnetic disks connected to them. The amount of force being transferred using a magnetic field is shown by the plastic strip's radial distance. This very affordable arrangement is simple to assemble, efficient, and appropriate for many programs that call for many trial kits.*

***Keywords***: *Magnometer; Teaching; Experimental; Newton's third law.*

## INTRODUCTION

Scientific idea learning in formal education is universally acknowledged as complex (Sands, 2021). The task at hand is even more challenging when new, first abstract descriptions of well-known occurrences must replace common sense explanations and experiences (Bhowmik, 2011). Newton's rules of mechanics serve as a prime illustration in this regard. Numerous investigations have been conducted to comprehend and enhance the machine-learning process (Costa & Muleri, 2014). Some guidelines call for creating experimental activities that extend students' perspectives, offer them the chance to engage with natural occurrences and allow them to exercise their independence in examining various circumstances (Susila et al., 2019). This tool supports the learning process even though it is insufficient for grasping the subjects (Hamdani et al., 2022b).

Several suggestions have been offered to make Newton's laws education more effective (Goiffon et al., 2009). Notice how Newton's third law receives a cursory treatment in most textbooks, whereas the first two laws receive significant attention (Halim, 2012). Since then, other works have significantly advanced the field (Yang, 2005). We may point to experimental approaches that address the impact of buoyancy as examples (El-Amin & Saad, 2017). Using a balance and a spring dynamometer, we can verify the buoyancy effect's pair of action and reaction forces, which is quite educational (Artiani et al., 2019).

The conservation of energy and the ideas of momentum are examined in collisions, which is another significant application of the third law (Seiler & Stamatescu, 2007). Since magnetic fields avoid mechanical contact between items and may have their magnitude adjusted by adjusting the distance between permanent magnets or electric currents in solenoids, they are an efficient means of exchanging forces between objects (Prayogi et al., 2021).

A grand experiment involves falling magnets reaching their terminal velocity inside an electrically conducting tube and exchanging forces via a magnetic field produced by eddy currents (Whitaker, 1998). Scales and balances are used in some methods. In contrast, other methods employ more complex apparatus, such as frictionless bead tables, high-voltage solenoids, smart energy sensors, and Arduino boards, to mention a few (Nurhasnah et al., 2022). We feel there are not enough concepts that employ highly inexpensive materials and directly exhibit the third rule's qualitative and quantitative components, even though they can investigate different facets of it. To do this, we created the tools listed above.

## RESEARCH METHODS

We created a substitute for a spring dynamometer that can transfer forces across a distance, enabling direct measurement of the force magnitude. One may prepare and conduct direct tests on crucial elements of Newton's equations, particularly the rule of action-reaction, using such a pair of magnetic dynamometers, henceforth referred to as "magnometer" (Zainuddin et al., 2022). The magnometer should have a low mass concerning the weight that will eventually be attached. In order to prevent mechanical contact throughout the experiment, they must simultaneously transfer the repulsive force in the order of their weight. The basic design of the magnometer is shown in Figure 1(a), which consists of two magnetic disks joined to either side by flat, flexible plastic strips (kept together by glue or magnetic attraction), which are fastened to a rectangular enclosure using double-sided tape. The optimum power output concentration of $35.10^6$ G Oe is available from the NdFeB alloy used in the magnetic disk (N35). The polypropylene folder cover's plastic strip is trimmed from there. The rigid plastic box has an open bottom. We marked it with "antenna set" and "container" on a rigid plastic box with a plastic strip and a magnetic disk.

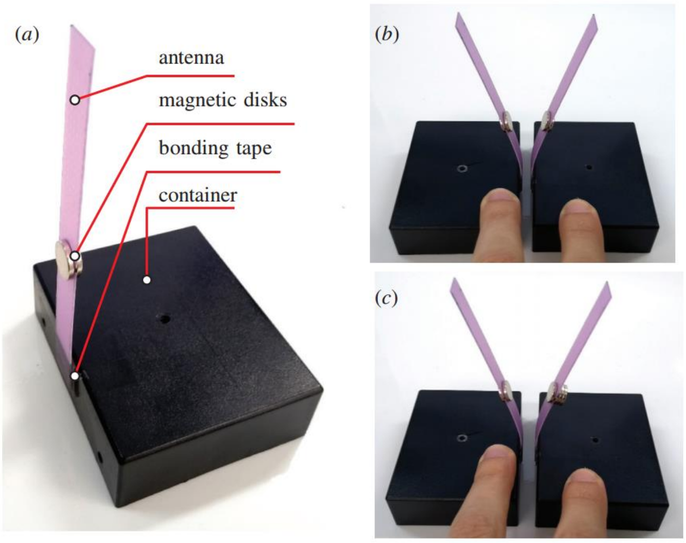


**Figure 1.** (a) Image of the magnometer. (b) Two magnometer with the same number of magnets on each side (two and two). The force investigated is shown by the antenna deflection angle. (c) Two magnometer with two and four magnets, respectively, each displaying an identical displacement for both antennas.

The fundamental interaction between two magnometer is shown in Figure 1(b). They were positioned side by side on the table. The magnets of the various magnometer are placed into anti-parallel alignment with one another in order to establish an attractive force between them and cause the antennas to deflect in opposite directions (Prayogi & Marzuki, 2022). Can each magnometer be equipped with various magnetic disks, as shown in Figure 1(c). The amount of force being transferred will alter depending on how close or far apart they are, changing how much the antenna deflects.

Figure 2 shows the horizontal forces affecting the interacting magnometer. Vectors of the same color act on the same body when two forces with subscripts swap according to the action-reaction pair (Colinge & Colinge, 2002). The subscript "12" denotes the horizontal component of the force delivered by the main magnometer to the secondary and vice versa (Dutta Gupta & Agarwal, 2017). The subscript "AC" denotes the force the antenna applies to the housing and vice versa (Prayogi, 2022). The external style used on the associated container is indicated by the "ext" subscript (Roslina et al., 2022). Since regular table styles exclude specific components, vertical styles are not displayed.

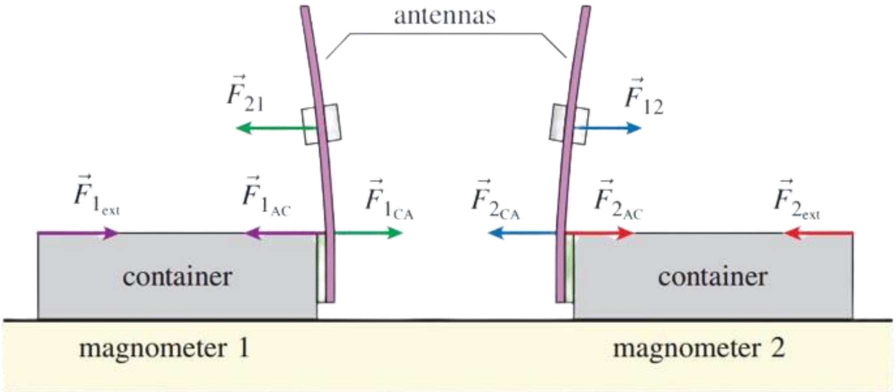


**Figure 2**. Illustration of the horizontal stresses on two interconnected magnometer.

The magnetism of the dish, its placement regarding the antenna's point of contact with the housing, and the necessary maximum deflection angle all play a role in determining the size of the plastic strip used as the antenna (Munazilah & Yulianto, 2021). A magnetic dish-mounted antenna's stiffness rises with its breadth, while the inverse is true of its height (Singh et al., 2022). We empirically determined a good force-deflection balance using the following values: (i) a rigid plastic box measuring 7.5 cm x 6.0 cm x 2.3 cm for the housing, (ii) an N35 magnetic dish measuring 10, 0 mm x 1.5 mm, and 0.9 g, attached 3.5 cm from the antenna contact point to the housing, and (iii) a 0.6 mm thick polypropylene strip measuring 10.0 cm x 1.2 cm for the antenna (Ghufron and& Prayogi, 2023). The ends of the connected tape are aligned with the housing's borders, and its length is at least as wide as the antenna.

## RESULTS AND DISCUSSION

Here, we outline several progressively more complicated applications that may be used in various settings, from elementary schools to college programs.

### Examine Newton's third law's qualitative features

An antenna can be checked to see if it bends in response to the force supplied to it as the first task for the class. Here, it is essential to realize that the equipment is a tool for measuring force. Students may achieve this by manually adjusting the distance between the two magnometer while being taught that the amount of "effort" required to keep the system stable increases as the antenna's deflection does (Hamdani et al., 2022). Figure 2 shows the results following the correlation $F_{1ext} = -F_{1AC}$, $F_{21} = -F_{1CA}$, and $F_{1ext} = -F_{21}$. It also applies to the second magnometer. Therefore, ignoring the interaction with the table, the student's hand generates an external force F1ext, equivalent to the force that the system exchanges magnetically and is denoted by an antenna.

Once students understand force measurement, they may use a small selection of magnetic disks across both devices. Since the condition is symmetrical, one would anticipate that the identical deflection on both magnometer would not result in a shock. The experiment may be repeated with more disks, but each device will experience the same results. As anticipated, a more significant deflection for the same separation will be seen. However, students probably made incorrect estimates if a variable quantity of disks were utilized in each magnometer. The typical reaction is that equipment with a foundational (with many more disks) will exert a higher force on the lower disk drives any opposing forces, and vice versa, as apparatus with a more significant number of disks is predicted to generate a stronger magnetic field (Adi et al., 2020). Newton's third law is demonstrated by the experimental finding that the deflection (and, consequently, the force) experienced by various devices is the same.

Magnometer reaction expectations for students. We ran a brief poll consisting of two questions, and the responses supported the students' expectations, as stated above. Suppose the number of magnetic disks in each magnometer was raised and combined two magnetic disks within one magnometer with six antennas inside the other. What would happen to the antenna's angular position (Syafutri et al., 2020)? These questions were posed after a description and illustration of the interactions between two magnometer with the same number of magnetic disks, as shown in Figure 1(b).

After students reply to each question, experimental demonstrations relevant to that topic's context are conducted. Due to this, we discovered that 16 outside from 24 students (67%) accurately responded that if both antennas could bend equally, the displacement would be greater than in the preceding example. The additional eight students (33%) correctly responded that its antenna would bend by the same amount as in the preceding scenario. However, they wrongly believed that this number would be the same. Responses for the second part of the questionnaire were very different: Less than two students (8%) correctly responded that both antennas still would bend in the same proportion. The remaining respondents (92%) indicated that one antenna would be crooked relative to the other.

**Measurement of forces**

The experiment shown in Figure 3, where the interconnection is placed, and the antenna is initially parallel to the table, will be performed to conduct a more complete investigation (Prayogi et al., 2019). Students find that the deflection angle rises when they add more magnetic disks to the antenna. Due to the magnetic disk's weight in this arrangement, the magnometer can study gravity forces. Attaching a stepwise scale parallel to the path of the directional antennas bend to a cardboard block will allow us to measure force. As shown in Figure 3, graduation may be calculated in magnetic disk weight units. The equilibrium position is marked with a new mark after three more disks. Each graduation equals 0.026 N of force or the weight of three magnetic disks. The red arrow represents the vector of gravitational acceleration.

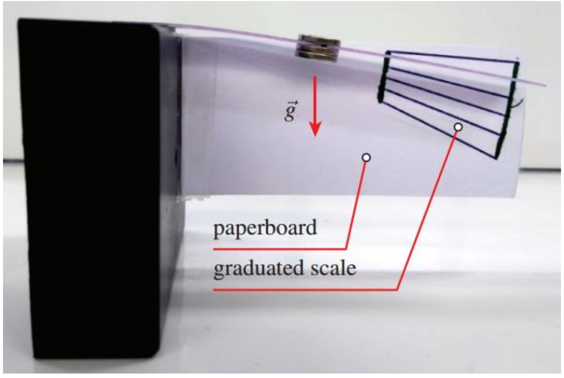


**Figure 3**. Measurement of the force the magnometer measured

Calculating the static friction coefficient between the magnometer and the table surface involves measuring forces and serves as an explanation. Figure 4 shows a curve corresponding to the maximum static force applied as a function of such normal force obtained from the experimental strategy previously outlined (Roslina et al., 2022). The angle coefficient produced by the linear fit is μs = 0,108 ± 0,004. This linear coefficient, which equates to a variation from zero in terms of the precision of the magnometer of 3.8%, was observed with an extrapolation mass of such a zero magnometer having a maximum static friction coefficient of 0.001 N. The outcomes reveal that the precision technology is far superior to that of the 0.026 N degrees chosen in terms of accuracy (Susilawati et al., 2021).

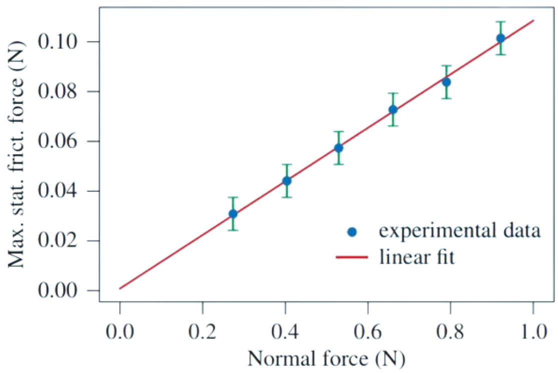


**Figure 4**. The results of the experiment on static friction. The horizontal coordinate error bars are lower than the size of the data symbol.

We conclude that the experimental findings' performance suggests that the exchanged action-reaction pair's resultant force can grow in response to an increase in the regular force's magnitude.

**Studying the forces acting on moving objects**

When the magnometer are in motion, the action-reaction laws may also be seen. Several configurations allow two magnometer to interact and provide freedom of movement in response to the exchanged pressures. We continued to adhere to a straightforward and efficient design, using two magnometer in such a tandem arrangement as illustrated in Figure 5 (a).

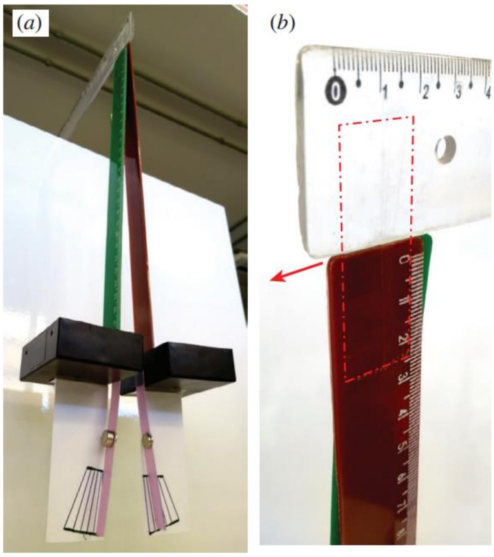


**Figure 5**. (a) Illustration of a pendulum made of two magnometer. (b) The pendulum supports in close-up.

The dashed red line indicated the bonding tape keeping the magnometer ruler in place. The red arrow shows the rotational axis of the pendulum. In such a setup, plastic rulers are affixed to the housing liner's sides using double-sided tape in the opposite and counterclockwise directions from the antenna (Hamdani et al., 2022). The opposing end of the ruler is attached to a fixed stand. An explanation of how the ruler is attached to the support in more detail is shown in Figure 5(b). A thicker ruler than the one linked to the magnometer is used as the support. Single-sided tape secures the set, allowing the magnometer ruler to rotate freely around the support axis while being secured in the transverse direction (Baldi et al., 2016). It is crucial to enforce this limitation to stop both devices from swiveling sideways while facing each other and getting drawn to magnetic disks on the other side.

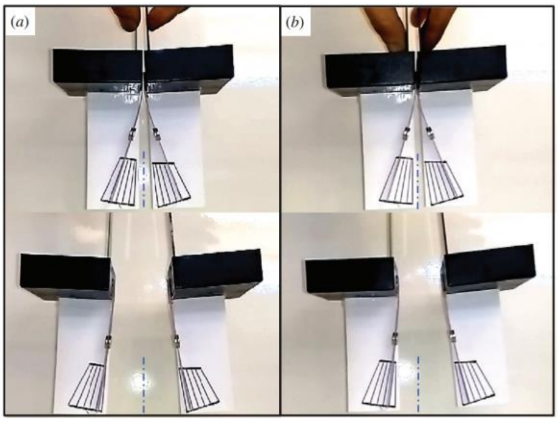


**Figure 6**. The beginning situation in the top photographs shows how the system is connected. (a) Equal magnometer weights and (b) An extra 40g, the system was rapidly freed, and mass was discovered inside the container at the left magnometer.

Holding two magnometer almost together and then rapidly releasing them will demonstrate Newton's second law, which states that an object's acceleration is proportionate to the amount of force applied to it and that the body's mass is the factor of proportionality (Prayogi et al., 2022). The two magnometer must thus move through the same magnitude during the same time if they possess the same mass, as shown in Figure 6 (a). As shown in Figure 6(b), if one is larger than the other, the dispersion will be more significant for the lighter one since both will encounter the same amount of exchange force in this situation (Alrasheed, 2019). To prevent this, we disregard gravitational forces, which have little bearing on the accuracy of the results for modest pendulum vibration amplitudes.

## CONCLUSION

To teach Newton's law of action-reaction, we have presented an experimental tool in this paper called a magnometer. Despite their simplicity, we have demonstrated that elusive experiments may be carried out with reliable findings. Students can directly participate in experimental tasks involving static arrangements, where they can watch the forces that the magnometer exchanges. Adjusting the number of magnetic disks, the distance between adjacent tools, and the position at which they are joined makes this feasible. Some adverse effects might make it difficult to achieve success in challenging circumstances. Among these is the air resistance on the antenna brought on by the movement of the magnometer. A more substantial antenna or a slower impact velocity might lessen this effect. When antennas are subjected to abrupt fluctuations in force, antenna oscillation is another unwanted characteristic that gentler hits can also lessen. Finally but not least, using too many magnetic disks in strongly connected magnometer might for the disk weight to significantly contribute to the amount of antenna displacement, which may result in an incorrect interpretation of the force-action connection.

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