Video-assisted experiment to observe interaction force during the interaction of two objects

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Video-assisted experiment to observe interaction force during the interaction of two objects

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Abstract
The momentum is often used to analyse the dynamics of the motion of an experimental interaction between objects. Meanwhile, the interaction force tends to be challenging to observe and obtain. In this study, a simple video-assisted experiment was used to observe the interaction forces during the interaction of two magnetic objects. The interaction force between magnetic dipoles was obtained for each object position during the interaction experiment. The maximum force interaction was obtained when the two objects were at the minimum distance. The velocity of the object significantly influences the minimum distance between two objects during the interaction. In addition, we found that the law of linear momentum conservation holds for this interaction. Furthermore, the total kinetic energy before and after the interaction is identical, indicating an elastic interaction. This study is hopefully beneficial for students to reduce the limitations in understanding the interaction forces between objects.

Keywords: interaction force, momentum, video analysis

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1. Introduction

The interaction of objects has become an essential topic on the subject of momentum in physics classes. Momentum is used to describe the dynamics of the motion of interacting objects. An interaction between two or more objects occurs in a concise time involving a relatively strong force [1, 2]. The magnitude of the force has an important role in the mechanism of interacting objects. Interactions do not always involve physical contact, but an interaction force between the objects must be occurred [3]. If the system of objects is isolated from the influence of external forces, the objects will exert interaction forces in opposite directions. As a result, the resultant force acting on the object system is zero or the total momentum is constant [4].

Using momentum, students can easily analyse the dynamics of motion from an interaction of object experiment. Quantities such as velocity and time can be obtained through measuring instruments so that the momentum of each object during the interaction experiment can be determined. Meanwhile, the magnitude of the force acting on each object tends to be difficult for students to observe during the interaction experiments. An attempt to solve this particular problem was carried out by experimentation in the laboratory. Interaction experiments such as using magnets can be carried out to observe the interaction forces on each object [5]. However, this magnetic force or magnetic induction force was very dependent on the position of each interacting object. Seeley and Shin used a vernier motion encoder cart and receiver laboratory device to record the position of each object during the interaction experiment [3].

Previous investigators have involved smartphone devices with various sensors to support teachers in conducting interaction experiments such as collisions. For example, the accelerometer sensor on a smartphone was used to analyse changes in momentum during collisions [6–10]. However, the interaction force when objects collide (or interact for collision without contact) is still one of the difficult quantities to be observed. In this study, we present a simple way of using video analysis to observe the interaction forces during the interaction of the two magnetic objects. This simple method can be a step for teachers and students to reduce limitations in learning the interaction of objects in physics classes.

2. Method

We observed the interaction force between two magnetic objects during the interaction without physical contact. We added thin cylindrical neodymium permanent magnets to both device parts called gliders as shown in figure 1(a). The neodymium magnets have a cylindrical radius $R = 1.2$ cm and a thickness $L = 0.2$ cm. We noted that the two combined masses consist of the glider and the attached magnet as $m_1 = 0.2068$ kg and $m_2 = 0.2072$ kg. The interaction between two magnetic forces is approximately yielded by the interaction between dipoles of a permanent magnet separated at a distance of x as illustrated in figure 1(b). We conducted three different types of interaction experiments, as illustrated in figure 2.

We used Gilbert Model to estimate the interaction of forces between magnetic dipoles (p) [11, 12]. Each piece of cylindrical magnet has $-p$ and $+p$ dipoles and their values are proportional to magnetization (M) as expressed in equation (1):

$$p = \pi R^2 M. \quad (1)$$

The interaction of forces between magnetic dipoles is the superposition of all the forces between the poles, as shown in equation (2):

$$\sum F = F_{32} + F_{31} + F_{42} + F_{41} \quad (2)$$

where for each interaction of forces between magnetic dipoles are shown in equations (2*a*)–(*d*):

$$F_{31} = +\frac{\mu_0}{4\pi}\frac{p^2}{x^2} = +\frac{\mu_0}{4\pi}\frac{\pi^2 R^4 M^2}{x^2} \quad (2a)$$

$$F_{32} = -\frac{\mu_0}{4\pi}\frac{p^2}{(L+x)^2} = -\frac{\mu_0}{4\pi}\frac{\pi^2 R^4 M^2}{(L+x)^2} \quad (2b)$$

$$F_{42} = -\frac{\mu_0}{4\pi}\frac{p^2}{(L+x)^2} = -\frac{\mu_0}{4\pi}\frac{\pi^2 R^4 M^2}{(L+x)^2} \quad (2c)$$

$$F_{41} = +\frac{\mu_0}{4\pi}\frac{p^2}{(2L+x)^2} = +\frac{\mu_0}{4\pi}\frac{\pi^2 R^4 M^2}{(2L+x)^2}. \quad (2d)$$

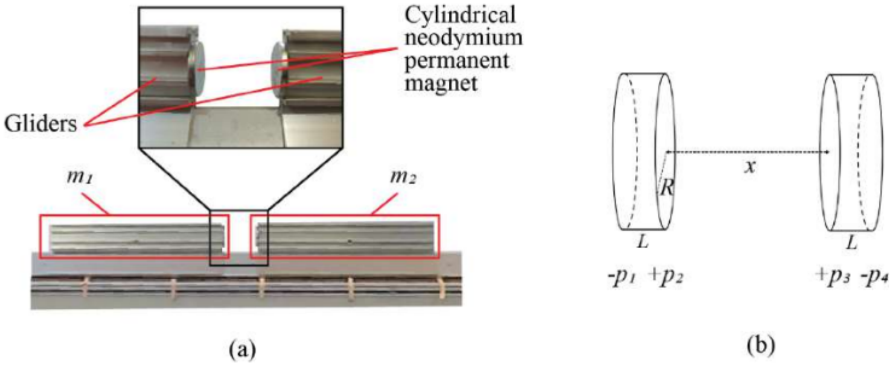

Figure 1. (a) Objects that were modified by adding two cylindrical neodymium magnets on two gliders; and (b) illustration approach between two cylindrical magnets with a distance x.

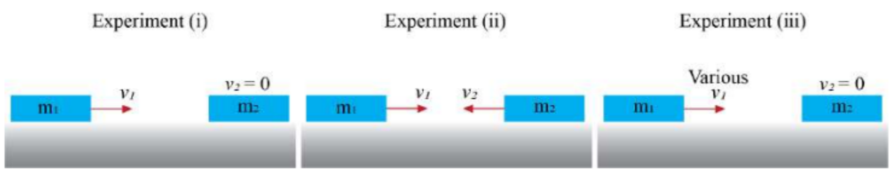

Figure 2. Three types of interaction experiments.

Thus, we could express the interaction of forces between magnetic dipoles in equation (2) by equation (3):

$$\sum F = \frac{\mu_0 \pi^2 R^4 M^2}{x^2}\left[\frac{1}{x^2} - \frac{2}{(L+x)^2} + \frac{1}{(2L+x)^2}\right]. \qquad (3)$$

Total interaction forces between magnetic dipoles can then be used to analyse dynamics of objects during interaction. We have conducted three types of one-dimensional interaction between two objects: (a) object m_1 traveling with a certain velocity to the object m_2 at rest, (b) two masses, m_1 and m_2 in an opposite direction and collide each other, and (c) object m_1 traveling with various velocities to the object m_2 at rest. Video shooting was taken during the experiment to analyse the positions of both objects m_1 and m_2 using Tracker software. The estimation of the interaction force is obtained by substituting the position of each object during the interaction experiment into equation (3). Besides that, we examined this interaction without contact through several physical quantities including total linear momentum and total kinetic energy.

3. Results and discussion

Repulsive forces between two similar magnetic poles created an interaction without physical contact. The two masses never touched each other during the interaction. Impact occurred between two magnetic forces yielded from the cylindrical neodymium magnets. The absence of physical contact during impact is indicated by the position of the masses. In experiment (i), the positions of objects m_1 and m_2 were obtained by video analysis using Tracker as plotted in figure 3(a). During the experiment, both m_1 and m_2 were never placed at similar positions which denoted that an interaction occurred without any physical contact. Graphical analysis resulted in the velocity of the objects from the slope of the position-time curve as shown in figure 3(a). In experiment (i), objects m_1 and m_2 were initially separated at $x = 0.7$ m and then

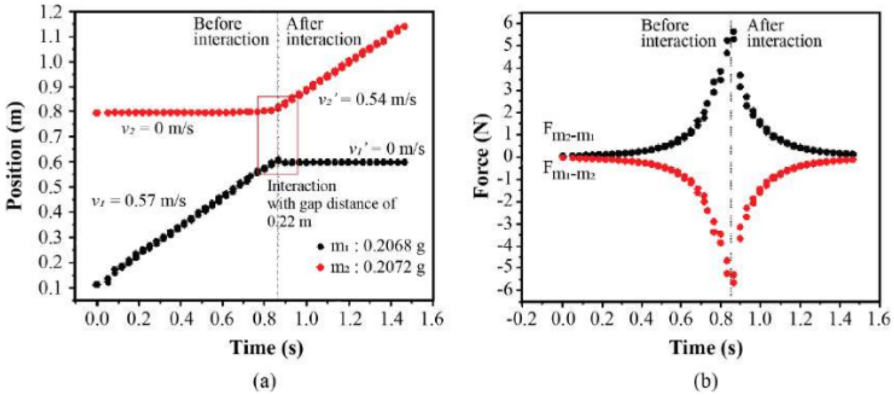

Figure 3. Experiment (i): (a) position of objects, and (b) interaction of forces between magnetic dipoles.

Table 1. Velocity, linear momentum, and kinetic energy at before and after interaction in experiment (i).

Interaction	Mass (kg) m_1	Mass (kg) m_2	Velocity (m s^{-1}) v_1	Velocity (m s^{-1}) v_2	Momentum (kg m s^{-1}) p_1	Momentum (kg m s^{-1}) p_2	Momentum (kg m s^{-1}) $\sum p$	Total kinetic energy (kg m^2 s^{-2})
Before	0.2068	0.2072	0.57	0	0.118	0	0.118	0.033
After			0	0.54	0	0.112	0.113	0.030
					Per cent change (%)		−4.24	−9.09

m_1 was traveling with velocities $v_1 = 0.57$ m s^{-1} to the m_2 at rest with $v_2 = 0$ m s^{-1}. The distance between two objects decreased until they interact with each other. Impact occurred while two masses were still separated at a minimum distance $x = 0.22$ m. It was clear that those two masses were experiencing interactions without physical contact. After interact, the two objects, m_1 and m_2 were then separated with wider distances as a function of time and they were traveling with individual velocity as $v_{1'} = 0$ m s^{-1} and $v_{2'} = 0.54$ m s^{-1} respectively. According to the observation and supported by $v_{1'}$, the interaction occurred without the recoil of m_1.

We consider the presence of a minimum distance between two masses during interaction is due to the interaction between magnetic forces, as the correlation is indicated in equation (3). Using this equation, the changes in the interaction of forces between magnetic dipoles during the experiment (i) can be obtained as given in figure 3(b). The interaction of forces between magnetic dipoles occurs when m_1 travels closer to m_2 and reaches a maximum at the minimum distance to object m_2. This maximum interaction of forces between magnetic dipoles occurred briefly. Figure 3(b) shows the interaction of forces curve between magnetic dipoles as a representation of action–reaction forces. This curve is identical to the action–reaction forces curve in common collisions with physical contact between two objects.

Furthermore, analysis of total linear momentum and total kinetic energy is required to examine whether they are true—or not true—for this interaction. In experiment (i), total linear momentum and kinetic energy before and after interaction are shown in table 1. Both total linear momentum and total kinetic energy before and after interaction are almost identical, which were 0.118 kg m s^{-1} and 0.112 kg m s^{-1} respectively, with per cent change of −4.24%. While total kinetic energy before and after interaction were 0.033 kg m^2 s^{-2} and 0.030 kg m^2 s^{-2} respectively with per cent change of −9.09%. Those results

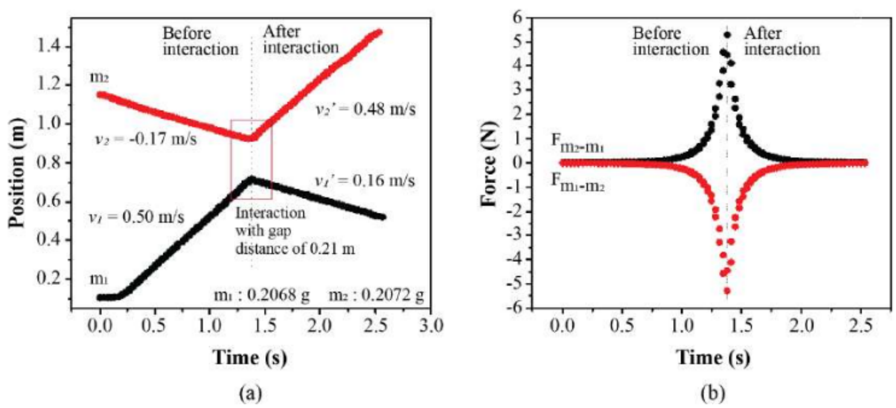

Figure 4. Experiment (ii): (a) position of objects, and (b) interaction of forces between magnetic dipoles.

Table 2. Velocity, linear momentum, and kinetic energy at before and after interaction in experiment (ii).

Interaction	Mass (kg) m_1	m_2	Velocity (m s^{-1}) v_1	v_2	Momentum (kg m s^{-1}) p_1	p_2	$\sum p$	Kinetic energy (kg m^2 s^{-2})
Before	0.2068	0.2072	0.50	−0.17	0.103	−0.035	0.068	0.029
After			−0.16	0.48	−0.033	0.099	0.066	0.026
					Per cent change (%)		−2.94	−10.34

indicate that the law of momentum conservation is true for interaction in experiment (i).

Similar outcomes were also provided by experiment (ii). In this experiment, both masses traveling in opposite direction with their individual velocity and interact each other without physical contact after a certain time. According to the graphical analysis of object position during interaction as plotted in figure 4(a), object m_1 was moving with velocity $v_1 = 0.50$ m s^{-1} and m_2 was traveling with velocity $v_2 = -0.17$ m s^{-1}. The distance between the masses was shortened until they interact with each other. Impact occurred while two masses were still separated at minimum distance of $x = 0.21$ m. Two masses were experiencing interaction without physical contact. After interaction, the masses were then separated with wider distances and traveling with their individual velocity as $v_{1'} = -0.16$ m s^{-1} and $v_{2'} = 0.48$ m s^{-1} respectively. The presence of a minimum distance between masses during impact is due to the maximum interaction forces between magnetic dipoles, which are mathematically related as in equation (3). Using this equation, the changes in the interaction of forces between magnetic dipoles during experiment (ii) can be obtained as figure 4(b).

In experiment (ii), total linear momentum and kinetic energy before and after interaction are shown in table 2. Both the total linear momentum and total kinetic energy of the masses before and after interaction are almost identical. Total linear momentum of the masses before and after interaction were 0.068 kg m s^{-1} and 0.066 kg m s^{-1} respectively, with per cent change of −2.94%. While total kinetic energy before and after interaction were 0.029 kg m^2 s^{-2} and 0.026 kg m^2 s^{-2} respectively with per cent change of −10.34%. Those results also indicate that even without physical contact, an interaction could also possibly have occurred. The law of momentum conservation is true for interaction in experiment (ii).

The object's velocity before interaction greatly affects to the closest distance between

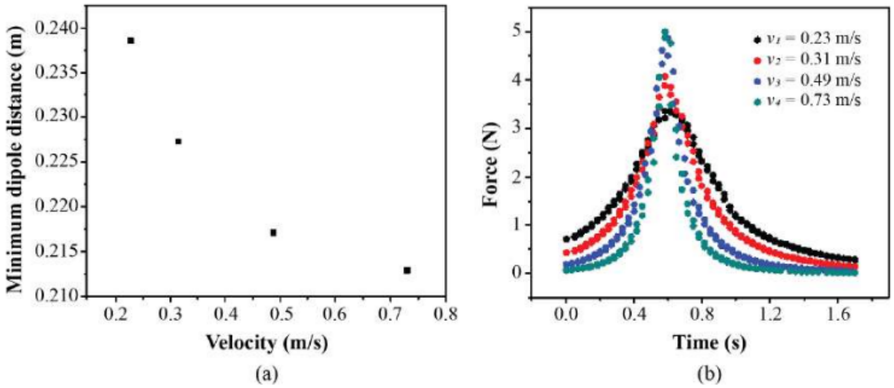

Figure 5. (a) Minimum distance between magnetic dipoles vs velocity, and (b) interaction of forces between magnetic dipoles vs velocity.

magnetic dipoles. The results of experiment (iii) showed that the minimum distance between magnetic dipoles is getting shorter when the object's velocity is higher as shown in figure 5(a). Object m_1 is moving with a velocity of 0.23 m s^{-1} towards object m_2 at rest and away 0.7 m from object m_1. The minimum distance between magnetic dipoles is 0.24 m. If m_1 is moving at a higher velocity, 0.73 m s^{-1}, the distance between magnetic dipoles is getting shorter, which is 0.21 m. Object m_1, which is moving with a higher velocity, yielded the closer distance between magnetic dipoles. The minimum distance between magnetic dipoles is getting shorter due to the higher velocity of the object that causes the greater interaction of forces between magnetic dipoles [3, 13–15]. This result is in accordance with the interaction of forces distributions between magnetic dipoles as shown in figure 5(b). An object moving at a higher velocity has a greater maximum interaction of forces between magnetic dipoles. However, the time for the interaction of forces between magnetic dipoles at a minimum distance goes to shorter when the object's velocity is higher.

Therefore, the three types of interaction without contact experiments have provided evidence that the interaction forces during the experiment can be observed. This study could possibly be beneficial for providing a simple way of using video analysis to study the interaction of objects with measurable physical quantities.

4. Conclusion

The interaction force of the interaction experiment without physical contact can be observed using a video analysis. The maximum force interaction is obtained when the two objects are at a minimum distance. The velocity of the objects greatly influences the minimum distance between two objects during the interaction before the interaction. This study shows a simple step to analyse the interaction of object experiments using a video analysis.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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