Experimental observation of permanent magnet rotation

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Abstract

Why does the Earth rotate? At present, it is impossible to use an experimental device to show which forces cause planets (such as Earth) to rotate in the solar system. Therefore, we developed a device to observe the rotation of a permanent magnet in a magnetic field to achieve an understanding of rotational force. A permanent magnet rotating under the action of a DC motor is installed on Motor Shaft; a permanent magnet designed to rotate in a magnetic field is placed in a circular container with water and floats on the surface of the water. Using the above setup, experimental methods and procedures based on this research can be used to observe the rotational behaviour of a permanent magnet in a magnetic field, understand the reason for its rotation, and determine the strength of the rotational force of the permanent magnet in the magnetic field.

Introduction

Why does the Earth rotate1,2? Many scholars have considered this question. In the 17th century, an accurate description of Earth’s rotation was provided via Newtonian mechanics. Today, it is common knowledge that the Earth rotates. However, which forces causes the Earth to rotate? Scientists believe that phenomena in the universe are controlled by two long-range forces, gravitation and electromagnetic forces. At present, several theories on the Earth's rotation remain as hypotheses3-5, and the driving forces of the Earth's rotation have not been mechanically processed. In teaching and scientific research, there are devices that simulate the rotation of the Earth, such as the apparatus of the Sun-Earth (-Moon) system or the apparatus of the eight planets in the solar system simulated. However, this does not help us observe how objects on the ground rotate with respect to each other under the influence of fundamental forces, let alone help us study which forces cause planets (such as Earth) to rotate in the solar system. The rapid development of modern electronics has led to the emergence of electronic products such as DC motors of various powers and speeds, AC/DC power adapters for controlling the speed of DC motors6, photoelectric digital tachometers (noncontact)7 and permanent magnets of various shapes and materials (grade)8,9. These developments led us to develop an experimental apparatus10-13. Through the interaction between permanent magnets, the rotation of permanent magnets in a magnetic field can be observed and understood and two different magnetic forces can be sensed with the hand, namely, the attractive force and the rotational force. This will contribute to the understanding of the rotational forces and provide an experimental basis for further improving the efficiency of the use of magnetic energy and developing mathematical models. This will help advance the development of devices that demonstrate the rotation of planets in the solar system.

The structure of this paper is as follows: In the results section, we list the experiments performed in Sections A–F and present our findings. In the conclusions section, we conclude the paper and summarize the key points. In the methods section, we detail the materials and design of the developed device and describe the experimental methods and procedures as well as the issues to be considered in the experiments.
In this study, a magnetic ball is installed at the motor shaft of a DC motor to make it rotate. We call it the motor-driven magnet, which is symbolized by $S_1$ and marked with $S_1$ on the motor-driven magnet. A magnetic ball designed to interact with a motor-driven magnet and rotate in a magnetic field. We call it the rotating magnet, which is symbolized by $M_1$ and marked as $M_1$ on the rotating magnet. The rotation distances of different features between $S_1$ and $M_1$ obtained by different experimental methods are symbolized by $r_1$ and $r_2$.

**Results**

**Magnet rotation**

In Experiment A, $M_1$ was placed on the same plane centred on $S_1$ when $S_1$ was rotating at 30 rpm. When using a bicoloured circle on $M_1$ as a reference frame and $M_1$ was between 10 and 42 cm from $S_1$, we observed that $M_1$, floating in a circular container, rotates due to the rotational torque of $S_1^{14,15}$. $M_1$ always rotated around an axis passing through its core, similar to the rotation of the Earth$^{16}$. Meanwhile, $M_1$'s axis of rotation wobbles around its core once in each cycle. This phenomenon was similar to the "Chandler wobble" shown by the Earth's axis of rotation$^{17}$. When the distance between $M_1$ and $S_1$ was 20–42 cm, $M_1$ would continue to rotate even if a 300 by 300 by 2 mm iron plate was placed in the middle between $S_1$ and $M_1$. When using a bicoloured circle on $M_1$ and the water surface used to float $M_1$ as a frame of reference, and allowing $M_1$ to approach or move away from $S_1$ within a range of 10–42 cm, we observed that during each cycle of $M_1$'s rotation, the orientation of $M_1$'s axis of rotation was at an angle of 85–90 degrees to the water surface where $M_1$ was floating. In other words, the orientation of $M_1$'s axis of rotation was always almost perpendicular to the water surface, regardless of how the distance between $M_1$ and $S_1$ varied in the range of 10–42 cm. As the distance between $M_1$ and $S_1$ varies between 10 and 42 cm, we observed that the angle between the circular surface of a bicoloured circle on $M_1$ and the surface of the water used to float $M_1$ also changes. For instance, if the distance from $M_1$ to $S_1$ was 10 cm, then the angle between the circular surface of a bicoloured circle on $M_1$ and the surface of the water in which $M_1$ was floating would be 85–90 degrees for each cycle of $M_1$'s rotation. If the distance from $M_1$ to $S_1$ was 42 cm, the angle between the circular surface of a bicoloured circle on $M_1$ and the surface of the water in which $M_1$ was floating would be 55–60 degrees for each cycle of $M_1$'s rotation. Based on the change in distance between $M_1$ and $S_1$, this caused a change in the angle between the circular surface of a bicoloured circle on $M_1$ and the surface of the water in which $M_1$ was floating, and also caused the position of the intersection of $M_1$'s axis of rotation on its sphere to change in an invisible manner. This phenomenon was similar to the "polar wandering" exhibited by the Earth's axis of rotation$^{18}$. When the rotating $M_1$ was in a fixed position within the range $S_1$ 10–42 cm, we gently applied a coloured paint dot to the axis of rotation of the $M_1$ sphere above the water surface. The coloured dot marked on the axis of rotation of $M_1$ was then used as a reference frame as the distance between $M_1$ and $S_1$ varied between 10 and 42, and in this way we observed change in position of the intersection of the axis of rotation of $M_1$ on
its sphere. When using the red and blue dots on $M_1$ representing the north and south magnetic poles and the surface of the water in which $M_1$ was floating as a frame of reference and allowing $M_1$ to approach or move away from $S_1$ within a range of 10–42 cm, we observed a change in the angle between the magnetic axis of $M_1$ and the surface of the water in which $M_1$ floats. For instance, if the distance between $M_1$ and $S_1$ was 10 cm, then the angle between $M_1$’s magnetic axis and the surface of the water in which $M_1$ was floating would be 0–5 degrees for each cycle of $M_1$’s rotation. If the distance between $M_1$ and $S_1$ was 42 cm, then the angle between $M_1$’s magnetic axis and the surface of the water in which $M_1$ was floating would be 55–60 degrees for each cycle of $M_1$’s rotation. In addition, the blue and red dots on $M_1$, used to represent the North and South Poles, always rotate around the axis of rotation of $M_1$. The experimental results show that in order to obtain the same results as in this study, the magnetic sphere representing $M_1$ must be placed in the centre of the hollow sphere and their centres of gravity must coincide. The magnetic sphere representing $M_1$ and the hollow sphere were standard spheres, otherwise different results would be generated.

Equal rotation period

In Experiment B, when the distance between $M_1$ and $S_1$ was 10–42 cm and $S_1$ rotated in a range of 30–60 rpm, we observed that during each cycle of $S_1$’s rotation, the south and north magnetic poles of $M_1$ corresponded to the north and south magnetic poles of $S_1$, and the rotation periods of $M_1$ and $S_1$ were equal. Furthermore, while $S_1$ rotates at a constant speed during each cycle, $M_1$ does not rotate at a constant speed; $M_1$ pauses for a moment during each cycle, after which it accelerates and continues its rotation. When the distance between $M_1$ and $S_1$ was 10–25 cm and $S_1$ was rotating in the range of 30–600 rpm, we observed that when $S_1$ accelerated, decelerated or stopped rotating, $M_1$ also accelerated, decelerated or stopped accordingly, and the rotation periods of $M_1$ and $S_1$ were equal.

Speed and distance

In Experiment C, whenever $S_1$ was rotated at 30, 90, 120, 240, 480 and 600 rpm, $M_1$, which was floating in a circular container and static, was allowed to slowly approach $S_1$ from 80 cm, and we measured and observed that the distance $r_1$ at which $M_1$ started its rotation as it approached $S_1$ was different. The results are shown in Table 1. The results show that when $S_1$ was rotating at the slowest speed of 30 rpm, the distance $r_1$ at which $M_1$ approached $S_1$ and started to rotate was 42 cm, this was the maximum distance at which $M_1$ started to rotate. When the distance between $M_1$ and $S_1$ was 42 cm, $S_1$ would have to rotate at 30 rpm or slower if $M_1$ was required to rotate.

Maximum distance

In Experiment D, $M_1$ floating in a circular container and rotating was moved from a position 10 cm from $S_1$ to a position further away whenever $S_1$ was rotated at 30, 90, 120, 240, 480 and 600 rpm, and we
measured and observed that the distance $r_2$ at which $M_1$ continued to rotate after moving away from $S_1$ was different. The results are shown in Table 2. The results show that when $S_1$ was rotating at 90 rpm, the distance $r_2$ at which $M_1$ continued to rotate after it slowly moved away from $S_1$ was 60 cm, this was the maximum distance at which $M_1$ continued to rotate.

Central angle and rotation

In Experiment E, we observed no rotation of $M_1$ when the motor shaft was linked at the 0 and 20 scales on the $S_1$ sphere. This occurred regardless of the orientation of $M_1$ relative to $S_1$, the rotational speed of $S_1$, and the distance between $S_1$ and $M_1$. When the motor shaft was linked at the 21 scale on the $S_1$ sphere, $M_1$ could not rotate within a range of 5–15 cm close to $S_1$ but could rotate within a range of 16–23 cm farther from $S_1$. When the motor shaft was linked at 45 scale on the $S_1$ sphere, $M_1$ could not rotate within a range of 5–9 cm close to $S_1$, but could rotate within a range of 10–32 cm farther from $S_1$. When the motor shaft was linked at the 57 scales on the $S_1$ sphere, $M_1$ could not rotate within a range of 5–7 cm close to $S_1$, but could rotate within a range of 8–34 cm farther from $S_1$. When the motor shaft was linked at 58 scale on the $S_1$ sphere, $M_1$ rotates in all ranges from 5–35 cm from $S_1$. When the motor shaft was linked at 90 scale on the $S_1$ sphere, $M_1$ rotates in all ranges from 5–42 cm from $S_1$. The experimental results show that the four equal arcs $NA$, $SA$, $NB$ and $SB$ with a scale of 0–90 on the $S_1$ sphere have the same effect and result on the rotation of $M_1$ caused by $S_1$. When the motor shaft was linked at the 0 to 57 scale on the $S_1$ sphere and $M_1$ was in a non-rotating state, $M_1$ would adhere to the container wall in the $S_1$ direction and wobble around its core.

Feeling the rotational force

In Experiment F, when the motor shaft was linked at 0 and 20 scales on the $S_1$ sphere, $M_1$ was allowed to approach or move away from $S_1$ and we could feel by hand that there was only an attractive force between $S_1$ and $M_1$. When the motor shaft was linked at 90 scale on $S_1$ sphere, allowing $M_1$ to approach or move away from $S_1$, we could feel two different magnetic forces between $S_1$ and $M_1$ by hand, namely the attractive force and the rotational force. When the motor shaft was linked at 21 to 90 scales on the $S_1$ sphere, allowing $M_1$ to approach or move away from $S_1$, we could feel the strength of the rotational force on $M_1$ by hand. As the linking point between the motor shaft and the $S_1$ sphere increases from 21 to 90 scales, the strength of the rotational force on $M_1$ increases. As the linking point on the motor shaft and $S_1$ sphere decrease from 90 to 21 scales, the strength of the rotational force on $M_1$ decreases. Also, as the distance between $S_1$ and $M_1$ decreases from 20 cm to 5 cm, the strength of the rotational and attractive forces between them gradually increases. As the distance between $S_1$ and $M_1$ increases from 5 cm to 20 cm, the strength of the rotational and attractive forces between them gradually decreases.
Conclusions

Based on the results obtained using the designed apparatus and the aforementioned experimental procedures, the following conclusions are presented:

M₁ floating in a circular container rotates due to the rotational torque of S₁, this would help to determine the relationship among the rotation of M₁ and the geometry of its magnet. As the distance between M₁ and S₁ changes, so does the angle between the circular surface of a bicoloured circle on M₁ and the surface of the water in which M₁ was floating, and this helps to determine the relationship among the intersection of M₁’s axis of rotation on its sphere and the distance between M₁ and S₁. As the distance between M₁ and S₁ changes, so does the angle between the orientation of M₁’s magnetic axis and the surface of the water in which M₁ was floating, and this helps to determine the relationship among the orientation of M₁’s magnetic axis and the distance between M₁ and S₁. When S₁ was rotated at different speeds, the rotation periods between M₁ and S₁ were equal, and this helped to determine the relationship that the rotation periods between M₁ and S₁ were equal. As S₁ rotated at different speeds, a resting M₁ was slowly moved to approach S₁, this caused M₁ to start rotating at different distances, this helped to determine the relationship among the distance that caused M₁ to start rotating and the speed of S₁. As S₁ rotated at different speeds, the spinning M₁ was slowly moved away from S₁, this resulted in M₁ continuing to rotate at different distances, this helped to determine the relationship among the maximum distance that resulted in M₁ continuing to rotate and the speed of S₁. M₁ did not rotate when the motor shaft was linked at scales from 0 to 20 on the S₁ sphere, this helped to determine the relationship among the non-rotational behaviour of M₁ and the central angle corresponding to scales from 0 to 20 on the S₁ sphere. When the motor shaft was linked at a scale of 21 to 57 on the S₁ sphere, M₁ would not rotate at distances close to S₁, but would rotate at relatively large distances, and this helped to determine the relationship between the non-rotational distance of M₁ close to S₁ and the synchronous rotational distance away from S₁ and the central angle corresponding to the 21 to 57 scale on the S₁ sphere. When the motor shaft was linked at a scale of 58 to 90 on the S₁ sphere, M₁ would be rotated over the entire distance it could be rotated, and this would help to determine the relationship between the total distance of synchronous rotation between M₁ and S₁ and the central angle corresponding to the 58 to 90 scale on the S₁ sphere. When the motor shaft was linked at 0 and 20 scales on the S₁ sphere, allowing M₁ to approach or move away from S₁, we could feel by hand only an attractive force between S₁ and M₁, this helped to determine the relationship between the absence of rotational forces between M₁ and S₁ and the central angle corresponding to the 0 to 20 scales on the S₁ sphere. When the motor shaft linked at the 21 to 90 scale on the S₁ sphere, allowing M₁ to approach or move away from S₁, we can feel the rotational force on M₁ and its strength by hand, this helps to determine the relationship between the rotational force on M₁ and its strength and the central angle corresponding to the 21 to 90 scale on the S₁ sphere. Using the above setup, permanent magnets of other materials (grades) and sizes can also be designed as motor-driven magnets and rotating magnets.
Methods

Design of permanent magnet rotations driven by a DC motor

A magnetic sphere was installed on the motor shaft of a DC motor with the centreline of the motor shaft passing through the centre of gravity of the magnetic sphere (DC motor model: ZYTD520, DC 24V, 5000 rpm, gearbox, ZGB37RG, DC 24V, rpm: 600). A circular base made of a non-ferromagnetic material was installed at the bottom end of the DC motor shaft. To aid observation and research, NdFeB magnetic spheres of 5 mm diameter material (grade) N42 were attracted and attached to a magnetic ball installed on a DC motor shaft in order to accurately locate the north and south poles of the magnetic ball installed on the motor shaft. A compass was then used to determine the north and south poles of the magnetic ball on the motor shaft, with the south pole marked with red paint as S and the north pole marked with blue paint as N. The speed of the DC motor was regulated by the AC/DC power adapter and its speed varied between stop, slow and fast (AC/DC power adapter model: MXD-24W024, INPUT: AC 100-240V 50/60Hz, OUTPUT: DC 1–24V 100–1000 mA). The magnetic sphere installed on the shaft of a DC motor for rotation, which we call the motor-driven magnet, was symbolized by \( S_1 \) and marked \( S_1 \) on the motor-driven magnet, see Fig. 1 left. \( S_1 \) was a NdFeB sphere with a material (grade) of N35.

Design of a permanent magnet rotating in a magnetic field

A magnetic sphere was placed and fixed in the centre of a hollow sphere made of a non-ferromagnetic material and it was ensured that the hollow sphere containing the magnetic sphere could float on the surface of the water. To aid observation and research, NdFeB magnetic spheres of 5 mm diameter material (grade) N42 were attracted and attached to the hollow sphere containing a magnetic sphere in order to accurately locate the North and South Poles on the hollow sphere containing a magnetic sphere. A compass was subsequently used to identify the north and south magnetic poles on the hollow sphere, with the south pole was marked with a dot of red paint, and the north pole was marked with a dot of blue paint. A circle was paint on the hollow sphere with circular surface perpendicular to the magnetic axis (similar to the Earth’s equator and magnetic axis). Half of this circle was painted red and the other half was painted blue. We call this sphere a rotating magnet, symbolized by \( M_1 \), and mark \( M_1 \) on the rotating magnet, see the sphere in the circular container on the right in Fig. 1. \( M_1 \) was a NdFeB magnet and the material (grade) was N42.

Design of magnet rotation caused by central angle
To find the key reason for the rotation of a permanent magnet. We take an arbitrary circle on the sphere of $S_1$ such that it passes through the North and South poles of $S_1$, thus generating NS and SN semicircles on the sphere of $S_1$ from the point N representing the North Pole and the points S representing the South Pole. We then take a point A on the NS semicircle to bisect the NS semicircle and a point B on the SN semicircle to bisect the SN semicircle. Thus, four arcs of equal length were generated on the circle of the $S_1$ sphere, namely the NA, SA, NB and SB arcs. Since the NA, SA, NB, and SB arcs on the circle of the $S_1$ sphere all correspond to a central Angle of 90 degrees. Therefore, we set points N and S on the circle on the $S_1$ sphere to 0 degrees and points A and B to 90 degrees. We also subdivide the NA, SA, NB and SB arcs into 90 equal parts and show the central angles using scale numbers from 0 to 90. The link interface between a DC motor shaft and the $S_1$ sphere can be set at any position between 0 and 90, see the sphere on the left in Fig. 1. When the motor shaft was linked at the scale from 0 to 90 on the $S_1$ sphere, the central axis of the motor shaft had to pass through the centre of gravity of the $S_1$ sphere to ensure that the DC motor equipped with $S_1$ was steady during rotation.

**Experimental setup and procedures**

The motor shaft of a DC motor was first linked at 90 scale on the $S_1$ sphere, namely point A or B on the $S_1$ sphere, and then $M_1$ was placed in a circular container with water and floated on the water surface, see Fig. 1. The speed of the DC motor was regulated by an AC/DC power adapter and caused the rotation of $S_1$ mounted on the motor shaft to vary between stop and 30 to 600 rpm. During the experiment, the minimum distance between $S_1$ and $M_1$ was 5cm and no other ferromagnetic objects not required for the experiment were allowed within 2 m. the ambient temperature was lower than 80°C.

In Experiment A, $M_1$ was placed on the same plane centred on $S_1$ when $S_1$ was rotating at 30 rpm. Using a bicoloured circle on $M_1$ as a reference frame and a distance of 10–42 cm between $M_1$ and $S_1$, we observed the behaviour of $M_1$ floating on the surface of the water in a circular container. Using a bicoloured circle on $M_1$ and the surface of the water in which $M_1$ was floating as a frame of reference, and allowing $M_1$ to approach or move away from $S_1$ within a range of 10–42 cm, we observed the angle between $M_1$’s axis of rotation and the surface of the water in which $M_1$ was floating, the change in angle that occurred between the circular surface of the bicoloured circle on $M_1$ and the surface of the water in which $M_1$ was floating, and the invisible change in the position of the intersection of $M_1$’s axis of rotation on its spherical surface. Using the red and blue dots on $M_1$ representing the north and south magnetic poles and the surface of the water in which $M_1$ was floating as a frame of reference, and allowing $M_1$ to approach or move away from $S_1$ within a range of 10–42 cm, we observed the angular change that occurred between the magnetic axis of $M_1$ and the surface of the water in which $M_1$ was floating, the position of the north and south magnetic poles on $M_1$ relative to the axis of rotation of $M_1$. According to the above method, the floating design of $M_1$ was not required if frictional resistance was not taken into account. To observe the rotational behaviour of $M_1$, a magnetic ball representing $M_1$ can be placed
directly in a circular transparent container with a smooth concave bottom or in the palm of the experimenter's hand.

In Experiment B, $M_1$ was placed on the same plane centred on $S_1$. The distance between $M_1$ and $S_1$ was $10–42$ cm and $S_1$ was regulated to rotate at a range of $30–60$ rpm. We observed the rotation periods of $S_1$ and $M_1$ as well as their respective rotational speeds. The distance between $M_1$ and $S_2$ was $10–25$ cm and $S_1$ was regulated to rotate at a range of $30–600$ rpm. As $S_1$ accelerated, decelerated and stopped rotating, we observed and measured the rotational periods of $S_1$ and $M_1$ with an optoelectronic digital tachometer.

In Experiment C, the distance between $M_1$ and $S_1$ in the same plane was $80$ cm. Whenever $S_1$ was regulated to rotate at $30, 90, 120, 240, 480$ and $600$ rpm, $M_1$, floating in a circular container and quiescent, was slowly approached from $80$ cm to $S_1$, and we measured the distance $r_1$ at which $M_1$ started its rotation as it approached $S_1$. Following the above method, $S_1$ could also be regulated to rotate at any speed from $30$ to $600$ rpm so that a resting $M_1$ slowly approaches $S_1$ from far to near to measure the distance $r_1$ at which $M_1$ starts to rotate as it approaches $S_1$.

In Experiment D, the initial distance between $M_1$ and $S_1$ was $10$ cm in the same plane centred on $S_1$. Whenever $S_1$ was regulated to rotate at $30, 90, 120, 240, 480$ and $600$ rpm, $M_1$, which was floating in a circular container and rotating, was moved further away from $S_1$ from a distance of $10$ cm, and we measured the maximum distance $r_2$ at which $M_1$ continued to rotate after it had moved away from $S_1$. Following the above method, $S_1$ can also be regulated to rotate at any speed from $30$ to $600$ rpm so that the rotating $M_1$ slowly moves away from $S_1$ from near to far to measure the maximum distance $r_2$ that $M_1$ continues to rotate after it has moved away from $S_1$.

In Experiment E, the motor shaft was linked to the $S_1$ sphere at the $0$ and $20$ scale, $S_1$ was regulated to rotate at any speed between $30$ and $600$ rpm, and $M_1$ was placed anywhere between $10$ and $30$ cm around $S_1$. We observed the behaviour of $M_1$ floating in a circular container. The speed of $S_1$ was regulated to $30$ rpm in the same plane centred on $S_1$. The motor shaft was linked at the $21, 45$ and $57$ scales on the $S_1$ sphere and $M_1$ was slowly moved from a distance of $5$ cm from $S_1$ to a position further away from $S_1$. We measured and observed the non-rotational distance of $M_1$ close to $S_1$ and the synchronous rotational distance of $M_1$ away from $S_1$. The speed of $S_1$ was regulated to $30$ rpm in the same plane centred on $S_1$. The motor shaft was linked at the $58$ and $90$ scales on the $S_1$ sphere and $M_1$ was slowly moved from a distance of $5$ cm from $S_1$ to a position further away from $S_1$. We measured and observed the entire distance $M_1$ could rotate after being moved away from $S_1$. Following the method described above, the speed of $S_1$ was regulated to $30$ rpm in the same plane centred on $S_1$. The motor shaft of the DC motor was then linked at the scales from $0$ to $90$ on the NA, SA, NB and SB arcs on the $S_1$ sphere to observe the rotational and non-rotational behaviour of $M_1$, measuring the non-rotational
distance close to $S_1$ after $M_1$ had been moved away from $S_1$ and its farther synchronous rotational distance, and the entire distance $M_1$ can rotate after it has been moved away from $S_1$.

In Experiment F, a DC motor equipped with $S_1$ was placed stably on the experimental table. In the same plane centred on $S_1$, $S_1$ was rotated at 30 rpm. We hold $M_1$ in our left or right hand and move it back and forth between 5 and 20 cm to bring it close to or away from $S_1$. The motor shaft was linked at the scales of 0 and 20 on the $S_1$ sphere, allowing $M_1$ to approach or move away from $S_1$, and we used our hands in order to feel the force between $M_1$ and $S_1$. The motor shaft was linked at a scale of 90 on the $S_1$ sphere, allowing $M_1$ to approach or move away from $S_1$, and we used our hands in order to feel the two different magnetic forces between $M_1$ and $S_1$\textsuperscript{37,38}. The motor shaft was linked at a scale of 21 to 90 on the $S_1$ sphere, allowing $M_1$ to approach or move away from $S_1$, and we used our hands in order to feel the strength of the rotational force on $M_1$. Following the above method, the motor shaft can also be linked anywhere on the $S_1$ sphere from 0–90 scale, while regulating $S_1$ to rotate at any speed from 30–600 rpm. Hold $M_1$ with our left or right hand and allow it to approach or move away from $S_1$ in order to feel the two different magnetic forces between $M_1$ and $S_1$ and their strength (when using additional permanent magnets of different materials and sizes to feel the two different magnetic forces between the motor-driven magnet and the rotating magnet, the size and magnetic strength of the motor drive magnet and the rotating magnet must not be too large at the same time. Otherwise, when the distance between the motor-driven magnet and the rotating magnet is relatively close, a hand cannot control the motor-driven magnet and the rotating magnet; they will cohere together instantly and may even cause damage to the hand and apparatus).

**Declarations**

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**AUTHOR CONTRIBUTIONS**

Weiming Tong designed the experimental device and analysed the experimental methods and procedures. Weiming Tong and Bihe Chen jointly measured and analysed the experimental data. Weiming Tong and Bihe Chen wrote the paper. They discussed the results and significance and commented on the manuscript.

**COMPETING INTERESTS**

There are no conflicts of interest to declare.
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Tables
Table 1
Shows the distance $r_1$ that causes $M_1$ to start rotating as resting $M_1$ slowly approaches $S_1$ from far to near in the same plane due to the following rotation speeds of $S_1$

| Motor-driven magnet | $S_1$ (rpm) | Rotating magnet | $M_1$ (rpm) | $r_1$ (cm) |
|--------------------|-------------|----------------|-------------|------------|
| $S_1$              | 30          | $M_1$          | 30          | 42         |
| $S_1$              | 90          | $M_1$          | 90          | 39         |
| $S_1$              | 120         | $M_1$          | 120         | 36         |
| $S_1$              | 240         | $M_1$          | 240         | 25         |
| $S_1$              | 480         | $M_1$          | 480         | 15         |
| $S_1$              | 600         | $M_1$          | 600         | 10         |

Table 2
Shows the distance $r_2$ that causes $M_1$ to continue to rotate as the rotating $M_1$ slowly moves away from $S_1$ from near to far in the same plane due to the following rotational speeds of $S_1$

| Motor-driven magnet | $S_1$ (rpm) | Rotating magnet | $M_1$ (rpm) | $r_2$ (cm) |
|--------------------|-------------|----------------|-------------|------------|
| $S_1$              | 30          | $M_1$          | 30          | 42         |
| $S_1$              | 90          | $M_1$          | 90          | 60         |
| $S_1$              | 120         | $M_1$          | 120         | 52         |
| $S_1$              | 240         | $M_1$          | 240         | 38         |
| $S_1$              | 480         | $M_1$          | 480         | 30         |
| $S_1$              | 600         | $M_1$          | 600         | 25         |

Figures
Figure 1

Experimental device for observing the rotation of permanent magnets\textsuperscript{10}

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

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