Experimental observation of permanent magnet rotation

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Abstract

Why does the Earth rotate? At present, several theories on Earth rotation remain hypotheses. Hence, the aim of this study was to obtain experimental evidence of the relationship between the rotational force and magnetic field so that we can use experimental devices to demonstrate the rotation relationship among the planets and the sun. Each permanent magnet rotating under the action of an external force is installed on the shaft of DC motor; each magnetic ball designed to rotate in a magnetic field is placed in the center of a hollow sphere that can float on the water. Using the above setup, the experimental methods and procedures based on this research can be used to observe the rotation 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.

Full Text

All astronomical objects in the solar system are known to rotate[1], similar to the Earth[2]. In the 17th century, an accurate description of the Earth rotation was provided via Newtonian mechanics. However, the driving force was not given a mechanistic treatment, and it was merely ascribed to a "push" by God. At present, several theories on Earth rotation remain hypotheses[3-5], and demonstrate the Earth rotational force through experiments is not possible. Magnetic fields are among the fundamental fields in nature and exist in the space around satellites, planets, stars, galaxies, currents, moving charges, permanent magnets, and varying electric fields. Although magnetic fields cannot be seen or touched, they can be studied based on their interactions with permanent magnets. The rapid development of modern electromagnetism has led to the emergence of electronic products, such as DC motor rotational speed control and photoelectric digital tachometers (noncontact)[6,7]. Permanent magnets of various shapes, sizes and materials are widely used in daily life[8,9]. With these developments, we now have the necessary tools to further explore magnetism[10-13].

The structure of this paper is as follows: In the results section, we list the experiments conducted 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 procedures followed to observe the magnetic sphere rotation under different parameters.

In this study, permanent magnets of different materials and parameters are installed on the shaft of a DC motor for rotation. These permanent magnets designed to be rotated on a DC motor are called the motor driven magnets. To distinguish the motor driven magnets with the same materials and parameters as well as those with different materials and parameters, they were named S_1, S_2, S_3 to S_{14} and marked on the motor driven magnets. Magnetic spheres of different materials and parameters are designed to rotate in a magnetic field. These magnetic spheres are called forced magnets. To distinguish forced magnets with the same material and parameters from those with different materials and parameters, they were named M_1, M_2, M_3 and M_4 and marked on the forced magnets.

Results

Magnetic sphere rotation

In experiment A, we observed that M_1 floating in the circular container starts to rotate because of the rotational torque of S_1[14,15]. Irrespective of where M_1 is located around S_1, M_1 always rotates around the axis passing through its core, similar to the rotation of the Earth[16]. When the distance between M_1 and S_1 is 35 cm, even if a 2 mm thick iron plate is placed between them, M_1 will also continue to rotate under the torque of S_1 rotation. Furthermore, its rotational axis "wobbles" once around its core during each cycle. This phenomenon is similar to the "Chandler wobble" and "polar wandering" exhibited by the Earth's rotation axis[17,18].

Magnet distance and speed

In experiment B, when S_1 rotates at a specific speed, slowly move the stationary M_1 from 80 cm to a position close to S_1. We observed that when S_1 rotates at 30 rpm, M_1 will start rotating in a circular container 42 cm away from S_1. When S_1 rotates at 120 rpm, M_1 will start rotating in a circular container 36 cm away from S_1. When S_1 rotates at 240 rpm, M_1 will start rotating in a circular container 25 cm away from S_1. When S_1 rotates at 480 rpm, M_1 will start rotating in a circular container 15 cm away from S_1. When S_1 rotates at 600 rpm, M_1 will start rotating in a circular container 10 cm away from S_1. As described above, when S_1 rotates at a specific speed, move M_1 from each starting rotation position to a position closer to S_1, and M_1 will continue to rotate. The results of this method show that when the distance between M_1 and S_1 is gradually increased from 10 cm to 42 cm, the speed of S_1 needs to be gradually reduced from 600 rpm to 30 rpm before M_1 can rotate. According to this method, we can use DC motors with different power and speed. Control the speed of the DC motor and allow the speed of S_1 to be higher than 600 rpm and lower than 30 rpm to measure and observe the relationship between the rotation of M_1 and the distance from M_1 to S_1 as well as the speed of S_1.

Synchronous rotation of magnets

In experiment C, we observe that in each rotation period of S_1, the S-poles and N-poles of M_1 correspond to the N-poles and S-poles of S_1 respectively. When S_1 accelerates, decelerates, or stops rotating, M_1 accordingly accelerates, decelerates, or stops. Therefore, M_1 and S_1 Synchronous rotation[19].

Maximum rotation distance

In experiment D, on the same plane centered on S_1: (1) When M_1 is at a different position centered on S_1, the speed of S_1 is controlled from stop to 30 rpm. We measure the first kind maximum rotation distance (r_1) between M_1 and S_1. (2) When the speed of S_1 increases from 30 rpm to 90 rpm, we slowly move M_1 from the position of r_1, the maximum rotation distance of the first kind, to the rotation place farther from S_1. We measure the second kind maximum distance rotation (r_2) between M_1 and S_1. When we perform permanent magnet rotation using S_1, S_2, M_1 and M_3 of different materials and parameters and M_1 and M_2, M_3 and M_4 of the same materials and parameters. We measured the two maximum rotation distances (r_1 and r_2) between S_1, S_2 and M_1, M_2, M_3 and M_4. The results are presented in Table 2. The results of this method show that when S_1 and S_2 rotate at 30 rpm, the distance between M_1, M_2, M_3 and M_4 and S_1 or S_2 shall not be greater than the maximum rotation distance (r_1) of the first kind. Otherwise, M_1, M_2, M_3, and M_4 will not rotate regularly. Even if the distance between M_1, M_2, M_3 and M_4 and S_1 or S_2 is greater than r_1 0.5–3 cm, M_1, M_2, M_3 and M_4 will not rotate regularly or just swing around their rotation axis. When S_1 and S_2 rotate at 90 rpm, the distance between M_1, M_2, M_3, M_4 and S_1 or S_2 cannot be greater than the second kind maximum rotation distance r_2. Otherwise, M_1, M_2, M_3, and M_4 will not rotate permanently. Even if the distance between M_1, M_2, M_3, M_4 and S_1 or S_2 is greater than r_2 0.5–5 cm, M_1, M_2, M_3, M_4 will not keep rotating for long. According to this method, permanent magnets with different materials and parameters can be used in the design, such as motor drive magnets and forced magnets. By controlling the electric motor speed and allowing the motor drive magnets to rotate at 30 rpm and 90 rpm, we can measure and observe the two maximum rotation distances (r_1 and r_2) between the forced magnet and the motor driven magnet.

Number of magnets and the rotation distance

In experiment E, when the same 12 magnets as S_3 is used, the number of motor driven magnets increases from 1 S_3 to 12 S_{14}, and the volume height (H) of the relative surface of the north and south poles also increases correspondingly. When each motor driven magnet in S_3 to S_{14} rotates at 30 rpm and 90 rpm respectively, we observe that with the increase of the number and volume height (H) of S_3 magnets, the two maximum rotation distances r_1 and r_2 of each motor driven magnet in M_1 and S_3 to S_{14} also increase correspondingly. The results are presented in Table 3. According to this method, a motor driven magnet can be a permanent magnet with the same material and parameters and the same geometrical shape (such as any square, rectangular, or circular magnet whose north and south poles are on opposite surfaces of the magnet), and different numbers. Then, the permanent magnet rotation is performed using different numbers of motor driven magnets and the same forced magnet. When each motor driven magnet rotates at 30 rpm and 90 rpm respectively, we can measure the two maximum rotation distances (r_1 and r_2) between the different numbers of motor driven magnets and the forced magnet.

Rotation direction and maximum rotation distance of magnet

In experiment F, on a circular section centered on the centroid of S_1 and coincides with the central axis of the DC motor. When the speed of S_1 is controlled at 30 rpm and 90 rpm, starting at 0° in the horizontal direction, we slowly moved M_1 from 10 cm near S_1 to a further distance. Then repeat at 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330°. We observe by measurement that the two maximum rotation distances (r_1 and r_2) between M_1 and S_1 differ at the above angles. The results are presented in Table 4. Based on the above method, we also observe that the direction of rotation of M_1 on the circular cross-section is different at different angles and distances[20]. However, it is the same for any pair of angles with a difference of 180°. Assuming that the radius from M_1 to S_1 is 20 cm. The rotation directions of M_1 are the same at 0° and 180° (opposite to the rotation direction of S_1), at 60° and 240° (perpendicular to the rotation direction of S_1), and at 90° and 270° (same as the direction of S_1).

Rotation of several magnetic spheres

In experiment G, on the horizontal plane centered on S_1, when the speed of S_1 is controlled at 90 rpm, let the rotating M_2 approach the rotating M_1 slowly, and we observe: (1) When the distance between M_1 and S_1 is 60 cm, the minimum distance between M_1 and M_2 such that they do not influence each other's rotation is 30 cm. When the distance between M_1 and S_1 is 30 cm, the minimum distance between M_1 and M_2 such that they do not influence each other's rotation is 20 cm. On a ray with S_1 centroid as its vertex, we arrange three M_1s to perform the rotation. The distances from M_1 to S_1 are 60 cm, 30 cm, and 10 cm, respectively. (2) When M_2 is located on one side of each M_1, and the distance between M_1 and S_1 is 60 cm, the minimum distance between M_1 and M_2 such that they do not influence each other's rotation is 24 cm. When the distance between M_1 and S_1 is 30 cm, the minimum distance between M_1 and M_2 such that they do not influence each other's rotation is 18 cm. When the distance between M_1 and S_1 is 10 cm, the minimum distance between M_1 and M_2 such that they do not influence each other's rotation is 8 cm. When three M_1s are placed on ray 60 cm, 30 cm and 10 cm away from S_1 with the centroid of S_1 as their vertex, one M_2 is placed on the left and right sides of each M_1.

In the plane centered on S_1, we arranged a total of three M_1s and six M_2s to perform the rotation. The results of this method show that we can measure the minimum distance between M_1 and M_2 without affecting each other's rotation by controlling the rotational speed of S_1 to be greater or less than 90 rpm. According to this method, permanent magnets with different materials and parameters can be designed as motor driven magnets and forced magnets. By controlling the DC motor speed and allowing the motor drive magnet to rotate at 90 rpm, we can measure the minimum distance between the forced magnets without influencing each other's rotation. Then, according to the materials and parameters of the permanent magnet, the center of mass of the motor driven magnet is taken as the vertex, and a corresponding number of the forced magnets are arranged on the ray to perform rotation. With the motor driven magnet as the center, a corresponding number of the forced magnets are arranged around the motor driven magnet to perform rotation[21].

Cause of magnetic sphere rotation

In experiment H, we observed that: (1) When we linked the top of the DC motor shaft to positions of 0° and 7° on the S_1 sphere, M_1 does not rotate. This occurs regardless of the orientation of M_1 relative to S_1, rotational speed of S_1, and distance between S_1 and M_1. Furthermore, M_1 will approach the container wall in the direction of S_1 and swing around its core in the circular container. (2) When we linked the top of the DC motor shaft to the positions of 8°, 30°, 45°, 60°, 80° and 90° on the S_1 sphere, the rotation period of M_1 and S_1 is the same. However, while S_1 rotates at constant angular speed on the DC motor shaft, M_1 does not rotate at constant angular speed around the rotation axis during each cycle. M_1 stops for an instant in each cycle and then speeds up again. Furthermore, M_1 rotates around its core in an oscillating manner. The rotational motion of M_1 is similar to the "astronomical nutation" exhibited by the Earth's rotational axis[22,23]. According to this method, magnetic spheres with different materials and parameters can be used to verify this result.

Feeling the rotational force

In experiment I, when the distance between M_1 and S_1 was varied between 5 and 20 cm. We are familiar with the strength of the attractive force between M_1 and S_1. Simultaneously, we can feel the strength of the rotational force of M_1 by hand[24-26]. When the distance between S_1 and M_1 decreases from 20 cm to 5 cm, the rotational force strength of M_1 increases. When the distance between S_1 and M_1 increases from 5 cm to 20 cm, the rotational force strength of M_1 decreases. Based on the above method, we can directly hold the non floating design M_1 in our hands. Under the rotation action of S_1, the attractive force and rotational force between M_1 and S_1 are felt by hand.

Conclusions

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

(1) With a motor driven magnet as the centre, the following behaviour of a forced magnet can be observed: the forced magnet rotates in the magnetic field under the rotational torque of the motor driven magnet. The rotation of the forced magnet depends on the rotational speed of the motor driven magnet and the distance between the forced magnet and the motor driven magnet. Synchronous rotation of the forced magnet and the motor driven magnet. By changing the spatial position of the forced magnet centred on the motor driven magnet, the rotation direction of the forced magnet is changed. With the motor driven magnet as the centre, several forced magnets rotate around the motor driven magnet.

The maximum rotation distances (r_1 and r_2) between the forced magnet and the motor driven magnet and the minimum distance between the forced magnets such that they do not influence each other's rotation can be determined. By changing the connection location between the top of the DC motor shaft and the 0°–90° on the motor driven magnet (magnetic sphere), the forced magnet can be rotated or its rotation can be stopped. This helps us to observe and identify two different magnetic forces, namely, the attractive force and rotational force between permanent magnets. This contributes to the comprehension of the magnetic phenomena in physical electromagnetism discussed in textbooks. This helps us further understand the magnetic field force and provides an experimental basis for further improving the efficiency of magnetic energy utilization and establishing mathematical models. (2) The experimental device and program can not only be used to observe and study the rotation of permanent magnets in a magnetic field but also to demonstrate the rotation relationship among the planets and the sun. When used to demonstrate the rotation relationship between the sun and planets, the motor driven magnets can represent the sun and the forced magnets can represent the planet. This will give a powerful boost to the development of apparatuses that demonstrate the relationship between the sun and the planets. In addition, the research provides an experimental basis for further research on the relationship between planetary rotation (such as the rotation of the Earth) and the magnetic field.

Methods

Design of permanent magnet rotation driven by a DC motor

Permanent magnets with different materials, parameters and geometrical shape is designed and can be installed on the top of the DC motor shaft[27,28,29]. When each permanent magnet is installed on the DC motor shaft, the centreline of the DC motor shaft passed through the barycenter of permanent magnet (DC motor model: ZYTD520, DC 24 V, 5000 rpm, gearbox, ZGB37RG, DC 24 V, rpm: 600). The DC motor base was round and made of nonmagnetic material. The round surface of the base was perpendicular to the rotation axis of the DC motor, making it stable when the base was placed on a horizontal surface, see Fig. 1[10]. The speed (stopped, slow, fast) of the DC motor was controlled using an AC/DC power adapter[30] (AC/DC power adapter model: MXD-24W024, INPUT: AC 100-240 V 50/60 Hz, OUTPUT: DC 1–24 V 100–1000 mA). S_1 and S_2 are magnetic spheres. S_3 is a rectangular magnet whose north and south poles are located on two opposite maximum planes. Each magnet from S_4 to S_{14} is a different number of combinations of the same S_3 magnets, which is bonded together by the mutual attraction of different magnetic poles. To facilitate observation and study, a compass is used to identify the north and south poles on S_1, S_2, S_3 to S_{14}. The south Pole is marked S with red paint and the north Pole is marked N with blue paint. Table 1 lists the permanent magnets named S_1, S_2 and S_3 and their corresponding magnetic materials and magnetic parameters. Table 2 lists the diameter (D) parameters of magnetic balls S_1 and S_2. Table 3 lists the length (L), width (W) and height (H) parameters of motor driven magnets S_3 to S_{14}.

Design of a permanent magnet rotating in a magnetic field

Magnetic spheres with different materials and parameters is placed and fixed in the center of non-magnetic hollow balls, each containing only one magnetic sphere[20,31], and ensure that the hollow ball containing the sphere can float on the water. To facilitate observation and study, a compass is used to identify the north and south poles on each magnetic sphere. The south Pole marked dot of red paint, and the north Pole dot of blue paint. A bisected circle perpendicular to the N–S pole axis (similar to the equator of the Earth) was then drawn on each magnetic sphere. One half of the bisected circle is marked with red paint and the other with blue paint, see Fig. 2. M_1 and M_2 are magnetic spheres with the same material and parameters, M_3 and M_4 are magnetic spheres with the same material and parameters, M_1 and M_3 are magnetic spheres with different materials and parameters[32–34]. During the experiment, each magnetic sphere was independent and could not stick to other magnets. Table 1 lists the magnetic spheres named M_1, M_2, M_3 and M_4 and their corresponding magnetic materials and magnetic parameters. The diameter parameters of magnetic spheres M_1, M_2, M_3 and M_4 are shown in Fig. 2.

Device for observing the reason for magnetic sphere rotation

Uses a magnetic sphere[35] (S_1). An arbitrary circle passing through the N and S poles was drawn on S_1, and two points, A and B, were selected in the NS and SN semicircles. The central angles of the NA, NB, SA, and SB arcs were all 90°. The N and S points were set as 0°, whereas points A and B were set as 90°. The subdivisions between 0° and 90° were then marked on the NA, NB, SA, and SB arcs. On the NA, NB, SA, SB arcs, the connection interface linked the top of the DC motor shaft can be set at any position between 0° and 90°. When the top of the rotating shaft of the DC motor is linked with any position between 0° and 90° on S_1; the centreline of the shaft passed through the centre of mass of S_1, see Fig. 1[10] (To further clearly observe and study the cause of rotation between permanent magnets, S_1 can be placed in the center of a non-ferromagnetic hollow sphere with a diameter greater than 8 cm and less than 15 cm).

Experimental setups and procedures

First, S_1 is mounted on top of the DC motor shaft, the top of the motor shaft is connected to point B (90°) on S_1, see Fig. 1. The N–S pole axis of S_1 perpendicular the rotating shaft. The AC/DC power adapter is used to control the rotation speed of the DC motor (stop, slow, fast) and allow the S_1 speed range to vary from 0 to 30–600 rpm[36]. Floatable M_1, M_2, M_3 and M_4 are placed in each transparent circular container containing water, see Fig. 1. During the experiment, the motor driven magnet and forced magnet were far from ferromagnetic objects, and the ambient temperature was below 80°C.

In experiment A, M_1 was placed 10–35 cm from the centre of S_1. Taking the horizontal plane in the transparent round container, marked magnetic poles and double-coloured circles on M_1 as the frame of reference[37]. When the speed of S_1 is controlled at 60 rpm, we observed the behaviour of M_1 in circular container.

In experiment B, on the same horizontal plane, the distance from M_1 to S_1 is 80 cm, and M_1 floating in the circular container is stationary. When the speed of S_1 is controlled at a specific speed of 30–600 rpm, we observe and record the speed of S_1 with photoelectric digital tachometer. When the speed of S_1 is controlled at 30 rpm, 120 rpm, 240 rpm, 480 rpm and 600 rpm, we slowly move M_1 from 80 cm to the position close to S_1 each time. Then, we observed and measured the relationship between the rotation of M_1 and the rotation speed of S_1, as well as the relationship between the distance of S_1 using a photoelectric digital tachometer and centimeter ruler. (When S_1 and M_1 get too close together, they will stick together instantly and even cause damage to the apparatus. Therefore, when we do this experiment, we have to control the distance between S_1 and M_1 to be more than 5 centimeters, so that S_1 and M_1 don't stick together).

In experiment C, with S_1 as the centre, M_1 was placed 10–35 cm from S_1. When the speed of S_1 is controlled at 30–60 rpm, we observed the respective rotation speed of M_1 and S_1. When the speed of S_1 is controlled at 61–600 rpm, we measured the rpm of S_1 and M_1 using photoelectric digital tachometer (noncontact).

In experiment D, on the same horizontal plane, with centimeters as the unit and S_1 as the center. Start at 10 cm from M_1 to S_1 and place M_1 in a different position away from S_1. (1) When M_1 is in a different position to S_1, first stop the rotation of S_1, M_1 is stationary, and then control S_1 to rotate at 30 rpm. We measure the first kind maximum rotation distance (r_1) between M_1 and S_1. (2) First, increase the speed of S_1 from 30 rpm to 90 rpm. Then slowly move M_1 from the position of r_1, the maximum rotation distance of the first kind, to the rotation place farther from S_1. We measure the second kind maximum distance rotation (r_2) between M_1 and S_1 (the minimum observation time for continuous rotation of M_1 is 24 hours). Based on the above method, S_1, S_2, M_1 and M_3 with different materials and parameters, and M_1 and M_2, M_3 and M_4 with the same materials and parameters are used for permanent magnet rotation. Then we measure the two maximum rotation distances (r_1 and r_2) between S_1, S_2 and M_1, M_2, M_3 and M_4 (avoiding the use of a ferromagnetic ruler for the measurements). The results are presented in Table 2.

In experiment E, first, linked S_3 to the top of the DC motor shaft, and the N–S polar axis of S_3 was set perpendicular to the DC motor shaft. Second, with S_3 as the middle, added the same magnet as S_3 one at a time on the N or S sides of S_3, 2 are S_4, 3 are S_5, until 12 are S_{14}. When the different magnetic poles of these permanent magnets attract each other and stick together, the N–S polar axis of the permanent magnets can be spontaneously maintained along the same straight line. Then on the same horizontal plane, place M_1 at different positions away from S_3 to S_{14}. When each motor driven magnets in S_3 to S_{14} are controlled to rotate at 30 rpm, we measured the first kind maximum rotation distance (r_1) between M_1 and S_3 to S_{14}. When the speed of each motor driven magnets in S_3 to S_{14} increases from 30 rpm to 90 rpm, we measured the second kind of maximum rotation distance (r_2) between M_1 and S_3 to S_{14}. The results are presented in Table 3. (When a high -strength large-size permanent magnet is used as the motor driven magnets, we should pay attention to the damage and inseparable consequences of the opponent. Because when permanent magnets are close to each other they spontaneously combine instantaneously).

In experiment F, taking the centroid of S_1 as the center of the circle, the circular section which coincides with the central axis of the DC motor was taken, and the horizontal direction was 0°. Starting at 0°, when the speed of S_1 is controlled at 30 rpm and 90 rpm, we slowly moved M_1 from 10 cm near S_1 to a further distance. Then repeat at 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330°. At the above angles, we measure the two maximum rotation distances (r_1 and r_2) between M_1 and S_1. The results are presented in Table 4. Based on the above methods, with the double-coloured circles on M_1 and the water surface of floating M_1 as the reference system. We observed the rotation direction of M_1 from different angles and compared it with the rotation direction of S_1.

In experiment G, on the same horizontal plane, with S_1 as the center, the rotation speed of S_1 is controlled to be 90 rpm. Under the torque of the rotation of S_1, M_1 and M_2 keep rotating at different positions around S_1. (1) When M_1 is 60 cm from S_1 and M_2 is 10 cm from S_1. M_2 was moved along the straight line passing through the centroid of S_1 and M_1 so that M_2 slowly approached M_1. Then we measured the minimum distance between M_1 and M_2 such that they do not influence each other's rotation. When M_1 is 30 cm from S_1 and M_2 is 10 cm from S_1. M_2 was moved along the straight line passing through the centroid of S_1 and M_1 so that M_2 slowly approached M_1. Then we measured the minimum distance between M_1 and M_2 such that they do not influence each other's rotation. On the ray with the centroid of S_1 as the vertex, several identical M_1 is arranged from far to near. Then, we calculate how many rotating M_1 can be arranged on the ray with S_1 centroid as its vertex. (2) The straight line passing through the centroid of S_1 and M_1 was used as the front-back reference frame. When M_1 is 60 cm away from S_1, allow M_2 to approach M_1 slowly on M_1 side. Then we measured the minimum distance between M_1 and M_2 such that they do not influence each other's rotation. When the distance between M_1 and S_1 is 30 cm or 10 cm, on the M_1 side, for 30 cm and 10 cm positions, we measured the minimum distance between M_1 and M_2 such that they do not influence each other's rotation. On the plane centered on S_1, three M_1s are arranged on a ray, its vertex is the centroid of S_1, distance from S_1 is 60 cm, 30 cm and 10 cm, and each M_2 is on one side of each M_1. Then, we calculated how many rotating M_1 and M_2 can be arranged on the plane centered on S_1.

In experiment H, in order to facilitate observation and research, S_1 is placed in the center of a non-ferromagnetic hollow sphere with a diameter of 8 cm. We set up several link interfaces on S_1 sphere, each of which can be linked to the top of the DC motor shaft. The linked positions of the N–B arc are 0°, 45°, and 90°, respectively. The linked positions of the S–A arc are 8°, 30°, 60°, and 80°, respectively. The S–B arc is 7°. (1) The distance between M_1 and S_1 is 10–35 cm, and the speed of S_1 is controlled at 30–600 rpm. Then, using the magnetic pole dots and double-coloured circles marked on M_1 as the frame of reference, linked the top of the DC motor shaft to the positions of 0° and 7° on S_1. We observe and record the behaviour of M_1. (2) On the same horizontal plane, the distance between M_1 and S_1 is 10–42 cm, and the speed of S_1 is controlled at 30 rpm. Then, using the magnetic pole dots and double-coloured circles marked on M_1 as the frame of reference, linked the top of the DC motor shaft to the positions of 8°, 30°, 45°, 60°, 80° and 90° on S_1. We observe and record the behaviour of M_1.

In experiment I, the DC motor was stably placed on the test bench. The top of the DC motor shaft is connected to point B (90°) on S_1, holding M_1 with our left or right hand. When the speed of S_1 is controlled at 30 rpm, the distance from M_1 to S_1 was varied between 5 and 20 cm. We then use our hands to feel the strength of the two different types of magnetic forces between M_1 and S_1[38,39]. (When using motor driven magnet and forced magnet with different materials and parameters for permanent magnet rotation, the volume and magnetic strength of motor driven magnet and forced magnet should not be too large at the same time. Otherwise, when the distance between the motor driven magnet and the forced magnet is relatively close, the hands cannot control the forced magnet; they will stick together instantly and even cause damage to the hands 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
Permanent magnets named S_1, S_2, S_3, M_1, M_2, M_3, M_4 and their corresponding magnetic materials and magnetic parameters

Name	Grade	Br		Hcb (BHC)		Hcj (IHC)		(BH) max	
		MT	kG	kA/m	kOe	kA/m	kOe	kJ/m³	MGOe
S_1	N35	1170/1210	11.7/12.1	876/899	11/11.3	≥955	≥12	263/279	33/36
S_2	N42	1290/1320	12.9/13.2	836/876	10.5/11	≥955	≥12	318/334	40/42
S_3	Y30	370/400	3.7/4.0	175/210	2.20/2.64	180/220	2.26/2.7	26.0/30.0	3.3/3.8
M_1	N42	1209/1320	12.9/13.2	836/876	10.5/11	≥955	≥12	318/334	40/42
M_2	N42	1209/1320	12.9/13.2	836/876	10.5/11	≥955	≥12	318/334	40/42
M_3	Y30	370/400	3.7/4.0	175/210	2.20/2.64	180/220	2.26/2.7	26.0/30.0	3.3/3.8
M_4	Y30	370/400	3.7/4.0	175/210	2.20/2.64	180/220	2.26/2.7	26.0/30.0	3.3/3.8

Table 2
Two maximum rotation distances r_1 and r_2 between S_1, S_2 and M_1, M_2, M_3 and M_4.

Name	D (mm)	n (rpm)	Name	r_1/r_2 (cm)
S_1	30	0-30/90	M_1	42/62
S_1	30	0-30/90	M_2	42/62
S_1	30	0-30/90	M_3	35/42
S_1	30	0-30/90	M_4	35/42
S_2	10	0-30/90	M_1	14/20
S_2	10	0-30/90	M_2	14/20
S_2	10	0-30/90	M_3	8/14
S_2	10	0-30/90	M_4	8/14

Table 3
As the number and volume height (H) of S_3 magnets increase, the two maximum rotation distances r_1 and r_2 for each the motor driven magnets in M_1 and S_3 to S_{14} also increase correspondingly

Name	S_3/quantity (block)	L/W/H (mm)	n (rpm)	Name	r_1/r_2 (cm)
S_3	1	50/50/25	30/90	M_1	45/66
S_4	2	50/50/50	30/90	M_1	60/86
S_5	3	50/50/75	30/90	M_1	70/98
S_6	4	50/50/100	30/90	M_1	78/110
S_7	5	50/50/125	30/90	M_1	84/122
S_8	6	50/50/150	30/90	M_1	88/132
S_9	7	50/50/175	30/90	M_1	92/142
S_{10}	8	50/50/200	30/90	M_1	95/150
S_{11}	9	50/50/225	30/90	M_1	98/156
S_{12}	10	50/50/250	30/90	M_1	101/162
S_{13}	11	50/50/275	30/90	M_1	104/168
S_{14}	12	50/50/300	30/90	M_1	106/172

Table 4
on a circular section centered on the centroid of S_1 and coincides with the central axis of the DC motor, the two maximum rotation distances r_1 and r_2 between M_1 and S_1 are the following angles

Name	●	n (rpm)	Name	r_1/r_2 (cm)
S_1	0°	30/90	M_1	42/62
S_1	30°	30/90	M_1	42/62
S_1	60°	30/90	M_1	30/52
S_1	90°	30/90	M_1	38/60
S_1	120°	30/90	M_1	30/52
S_1	150°	30/90	M_1	42/62
S_1	180°	30/90	M_1	42/62
S_1	210°	30/90	M_1	42/62
S_1	240°	30/90	M_1	30/52
S_1	270°	30/90	M_1	32/50
S_1	300°	30/90	M_1	30/52
S_1	330°	30/90	M_1	42/62

Figures

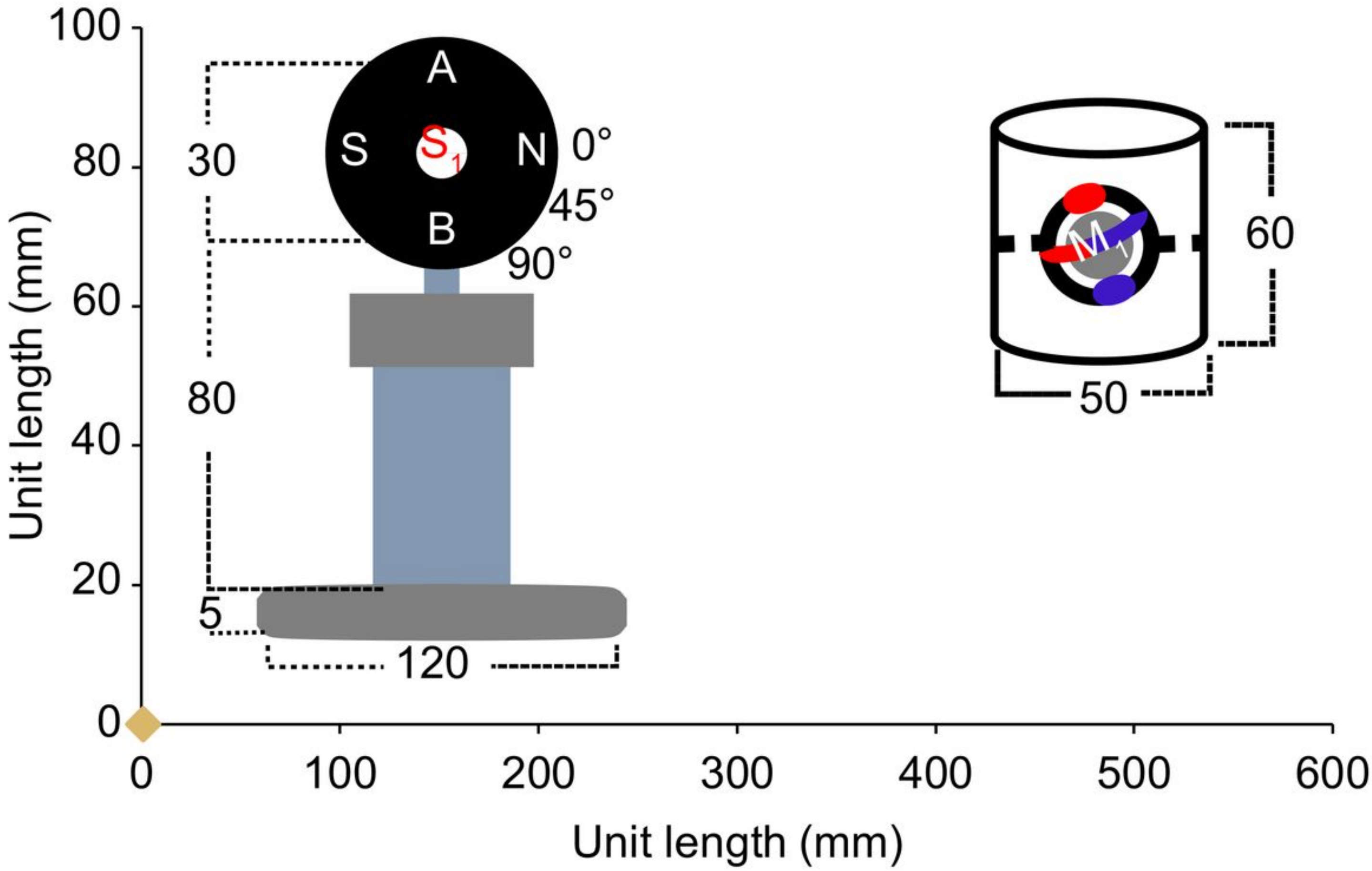

Figure 1

Experimental device for observing the rotation of permanent magnets[10]

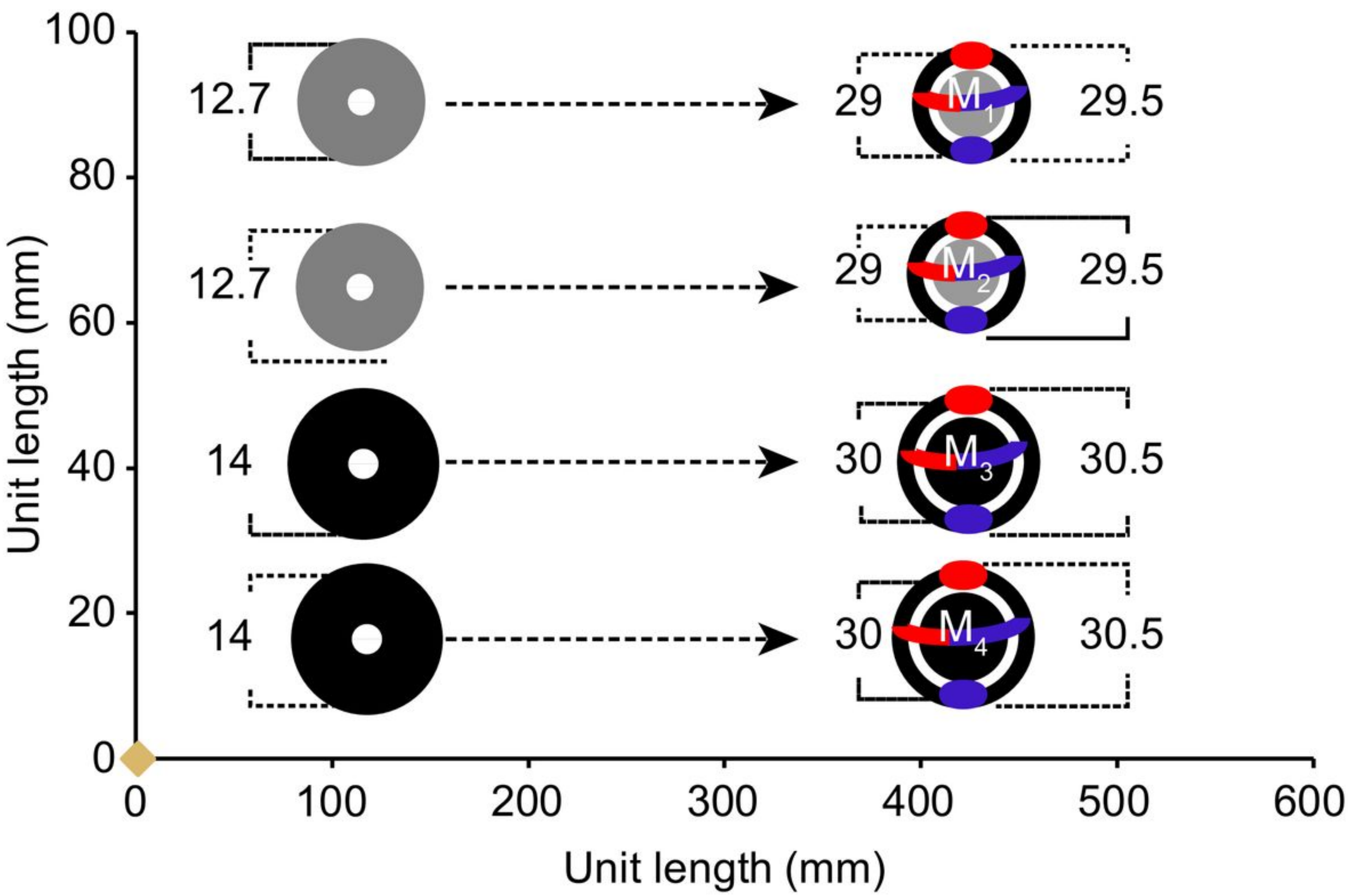

Figure 2

Design of permanent magnets that rotates in a magnetic field

Supplementary Files

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- A.Magneticsphererotation.mp4
- B.Magnetdistanceandspeed.mp4
- C.Synchronousrotationofmagnets.mp4
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- F.Rotationdirectionandmaximumrotationdistanceofmagnet.mp4
- G.Rotationofseveralmagneticspheres.mp4
- H.Causeofmagneticsphererotation.mp4
- I.Feelingtherotationalforce.mp4