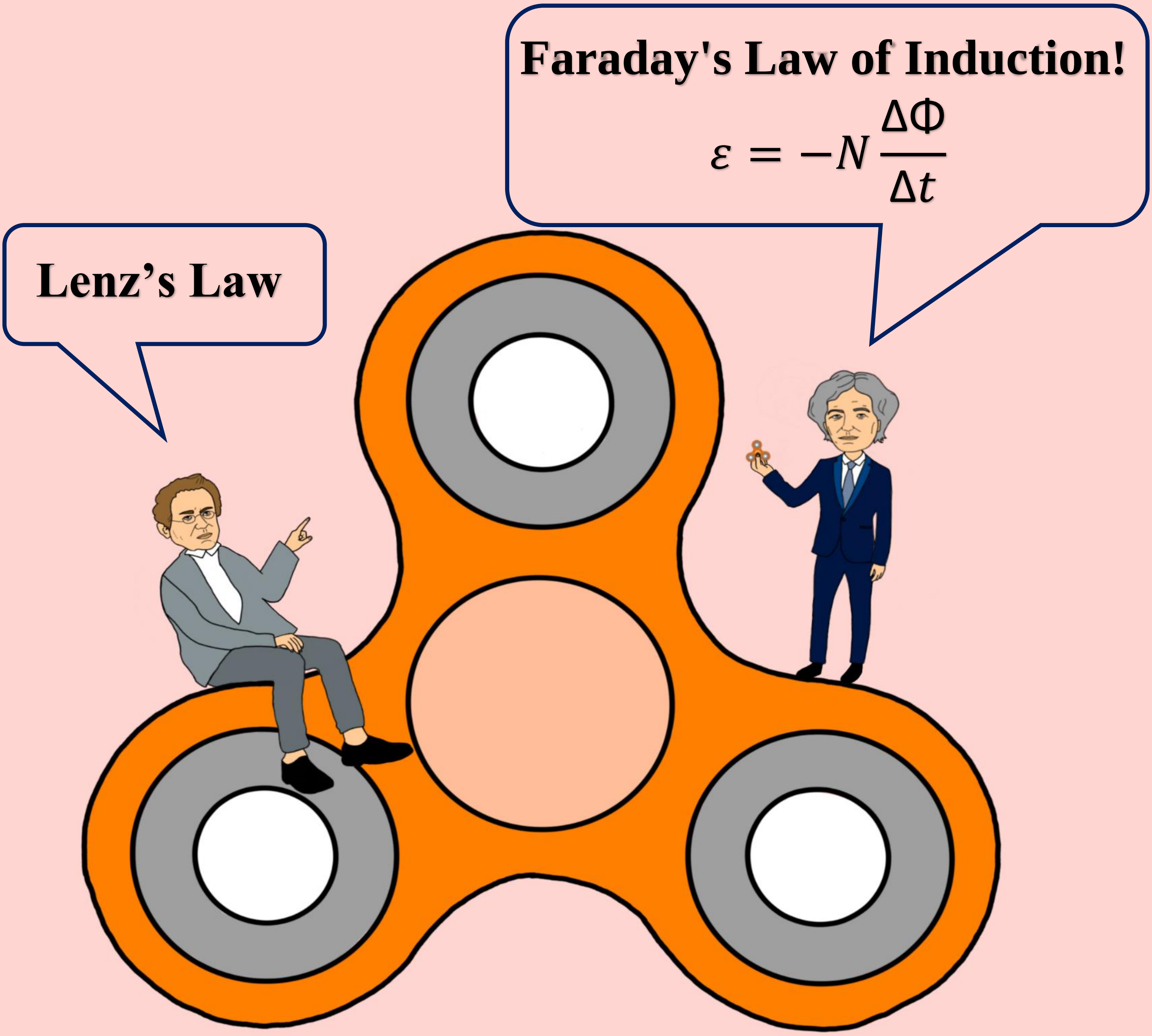
Visualizing Electromagnetism through Fidget Spinner

磁電定律 「螺」俾你睇



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Faculty of Education
The University of Hong Kong
香港大學教育學院

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Teacher's Manual
<u>Fidget Spinner Experiment</u>

Topic: Electromagnetic Induction

Aims:
- To demonstrate Lenz's Law and Faraday's Law
- To illustrate the factors that affect the magnitude of induced e.m.f. and current

Student's Prior Knowledge: Ohm's Law, Electromagnetism, Faraday's Law, Lenz's Law

Experimental Apparatus:

Apparatus/Materials	Quantity
Fidget Spinner	2
Thin magnets	3
Strong (neodymium) magnet	3
Aluminium foil (20 layers)	1
Copper plate	1
Coil with 12,000 turns	1
LED light bulb	1
Stopwatch	1
Hair dryer	1

Experimental Set-up and Teaching Procedure:

<u>Demonstration (Part I)</u>:

1. Set up the apparatus as shown in Figure 1.

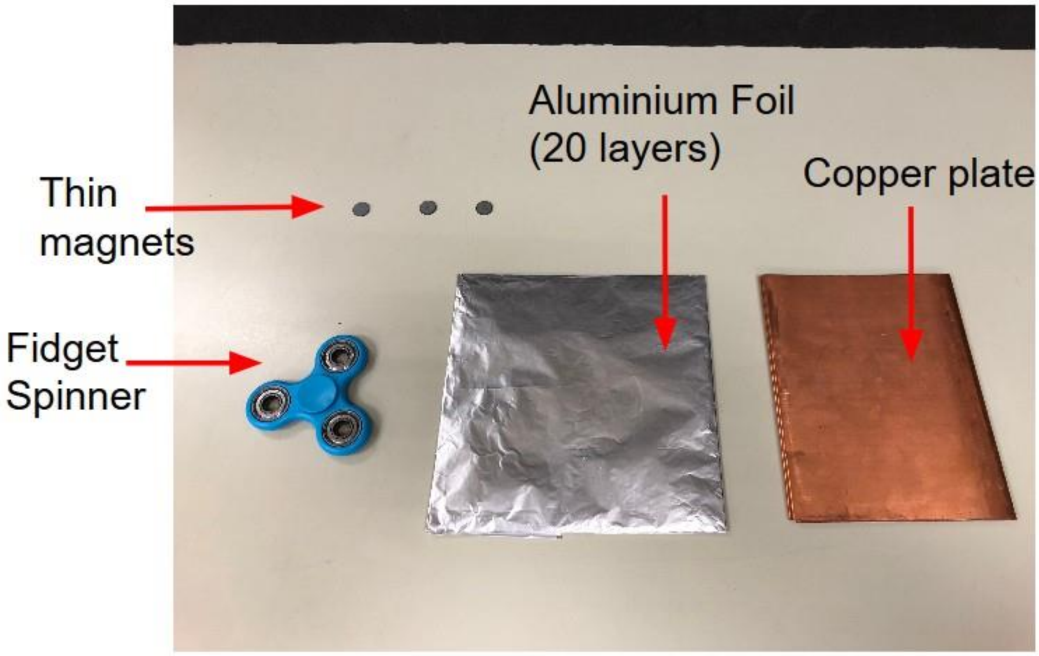


Figure 1: Experimental set-up for the demonstration of Lenz's Law

2. Invite a student to put a bar magnet near the aluminium foil and copper plate to show that these metals have no attraction with magnets.

3. Invite a student to rotate the fidget spinner on a wood table and ask students to record the duration before the spinner stops rotating completely.

4. Place the fidget spinner on aluminium foil. Invite the class to predict the duration of the spinner's rotation on the aluminium foil, then invite the same student to rotate the spinner. A significant decrease in rotation time should be observed.

5. Repeat Step 3 on a copper plate. A further decrease in rotation time should be observed.

6. Ask the class to explain the difference in rotation time of the spinner by using six note cards (see Appendix). Teachers may prepare note cards explaining the phenomenon and ask students to rearrange them to make sure that every student is involved in the activity.

Demonstration (Part II):

1. Set up the apparatus as shown in Figure 2.

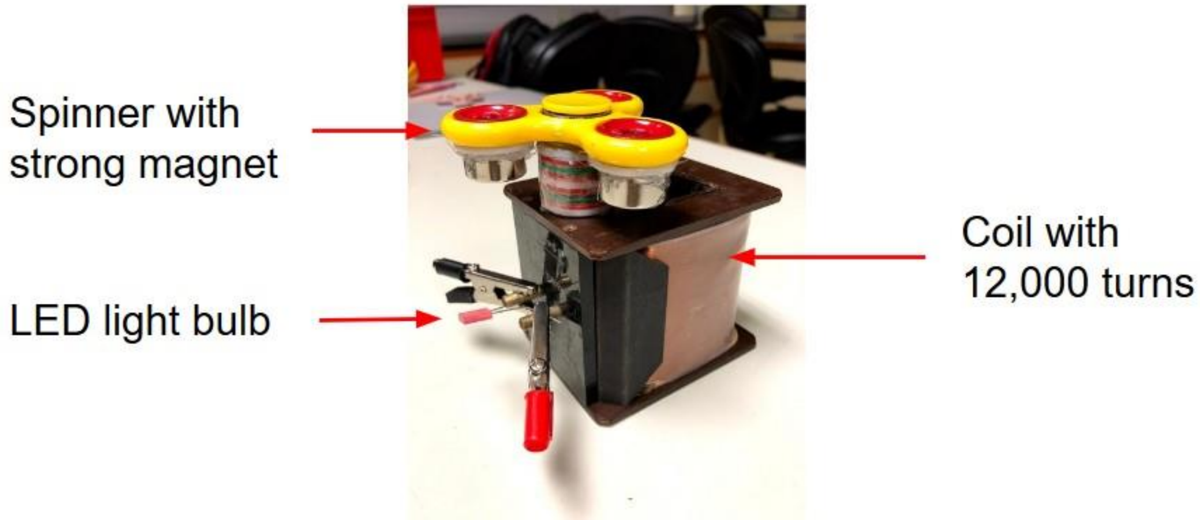


Figure 2: Experimental set-up for the demonstration on Faraday's Law

2. Investigate the fine structure of the setup with students. Explain that strong magnets are attached to the bottom of the spinner, and the box-like apparatus is a coil with 12,000 turns.

3. Instruct students to be aware of the change in LED brightness while the spinner is i) accelerating; ii) decelerating.

4. Use the hair dryer to accelerate the fidget spinner. After the spinner reaches a constant speed for a while, or the brightness of the LED becomes constant, turn off the hair dryer.

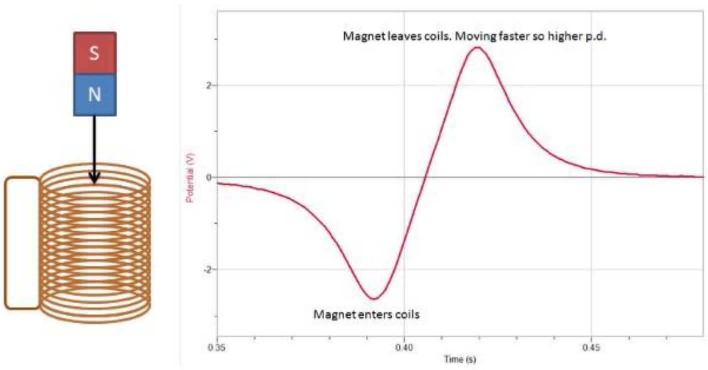
5. Invite students to state their observation of the change in the brightness of the LED when it is accelerated by the hair dryer. A gradual increase in brightness should be seen. Ask students to explain the change in brightness by applying the theories learnt in the last lesson (Faraday's Law).

6. Again, invite students to state their observation of the change in brightness of the LED light bulb after switching off the hair dryer. This time, a gradual decrease in brightness should be seen as the fidget spinner decelerates. Ask students to explain the change of brightness by applying the theories learnt in the last lesson (Faraday's Law).

Rationale:

<u>Demonstration (Part I)</u>:

1. The conventional example for demonstrating Lenz's Law is to drop a bar magnet through a coil and record the change in voltage by a data logger.

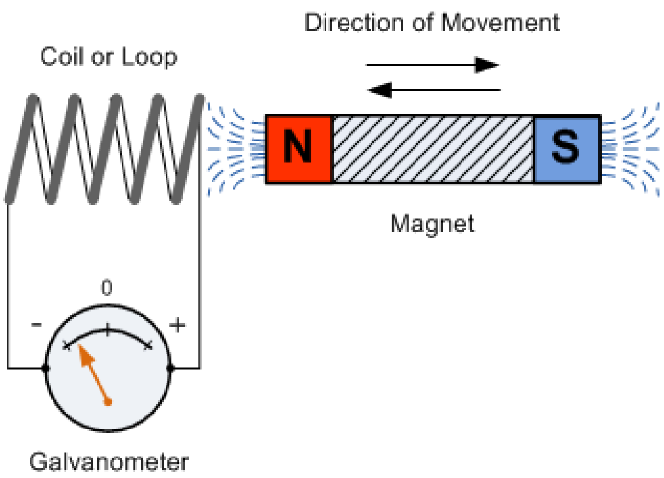


2. However, the naked eye is unlikely to capture the subtle change in motion of the bar magnet as it is still falling. On the other hand, by using a fidget spinner, the effect of opposing the change of B-flux can be directly visualised by the deceleration of the spinner. Since no data logging is involved, students can understand the demonstration without a strong background in graph interpretation.

3. Students may have an alternative conception that **current** is always induced whenever a conductor experiences a change in magnetic flux. However, it should be the **e.m.f.** being induced. To clarify this misconception, two different metal plates (aluminium and copper) are used in the demonstration. The fidget spinner rotates significantly longer on aluminium foil, which can only be explained by the difference in resistivity of aluminium and copper ($V=IR$). The teacher can then utilise the teachable moment to emphasise that a change in magnetic flux would induce e.m.f, while the magnitude/existence of induced current depends on other factors.

Demonstration (Part II):

1. The conventional sample for demonstrating Faraday's law is to connect a wire loop to a galvanometer and move a bar magnet in and out of the loop[1].



2. However, the above demonstration focuses on detailed calculation rather than visualisation of a changing magnetic field on the induced e.m.f.. It only demonstrates the change in readings of current on the galvanometer, and the speed of the magnet is changing.

3. On the other hand, the proposed setup enables students to observe the change in e.m.f. by the relative brightness of the connected LED while the spinner is rotating at a different speed. Students could then better understand the factors affecting the resultant induced e.m.f..

Precautions

1. Beware of the strong attraction between neodymium magnets.

2. Choose the "cool air" setting for the hair dryer to avoid overheating.

Further Investigation

1. If students are curious whether the magnetic susceptibility of the metal will affect the induced current, the teacher can use a strong magnet to prove that the only contributing factor is the electrical resistivity of the metal.

2. Teacher may ask students how the set-up can be refined to make the LED glows brighter. For example, the teacher may ask students to think about how the number of turns of the coil would affect the resultant e.m.f..

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[1] Tong S S, Won H K, Kwong P K, Wong Y L & Lee L C (2009). Electricity and Magnetism, New Senior Secondary Physics in Life. Pearson Education Asia Ltd.

Appendix:

Note Cards

The magnets rotate

Change in magnetic flux

An e.m.f. is induced in metal plate

Induce a current in metal plate

By Lenz's Law, the induced current flows in direction opposing the change

The Spinner stops rotating very soon

電磁感應
手指陀螺實驗工作紙

姓名:________________(　　)　　　　　班別:________　　　　　日期:_____________

目的

- 演示楞次定律及法拉第定律。
- 研究影響感生電動勢和感生電流的大小的因素。

熱身問題

1. 試寫出楞次定律。

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2. 線圈中磁通量的改變速率如何影響感生電動勢的大小？

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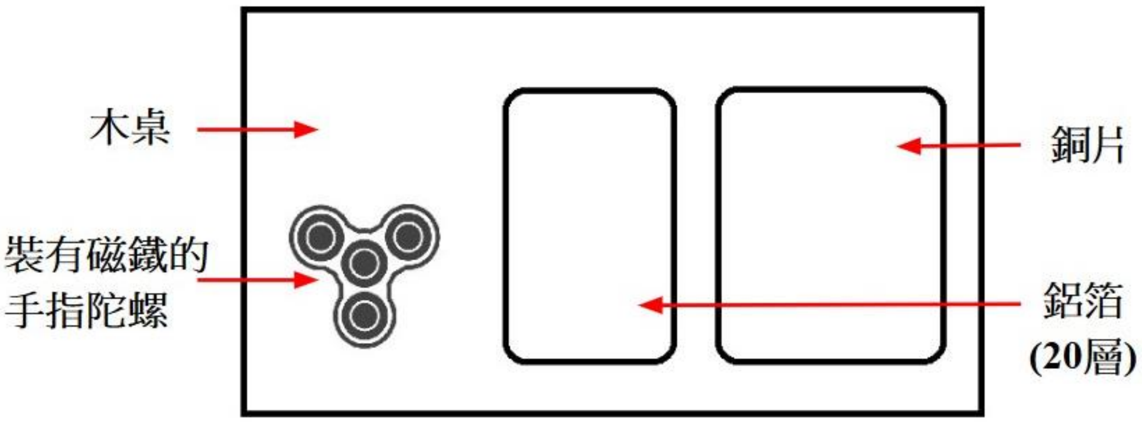
第一部份
實驗器材及裝置：



裝有磁鐵的手指陀螺
木桌
鋁箔（20 層）
銅片

實驗步驟:

1. 將三塊薄磁鐵固定於手指陀螺的底部。
2. 在木桌上轉動陀螺，記錄轉動的時間。
3. 改用鋁箔和銅片，重覆步驟 2。

假設

哪個裝置（木桌/鋁箔/銅片）中的陀螺最快停止轉動？為什麼？

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觀察

在下面的表格中記錄陀螺完全停止轉動所需的時間。

陀螺的位置	轉動的時間 (秒)		
	1	2	3
木桌上			
鋁箔上			
銅片上			

陀螺在 ___________________ 上轉動的時間最短。

討論

1. 為什麼在金屬片上的陀螺會較早停止轉動？
   （提示：試用楞次定律解釋）

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____

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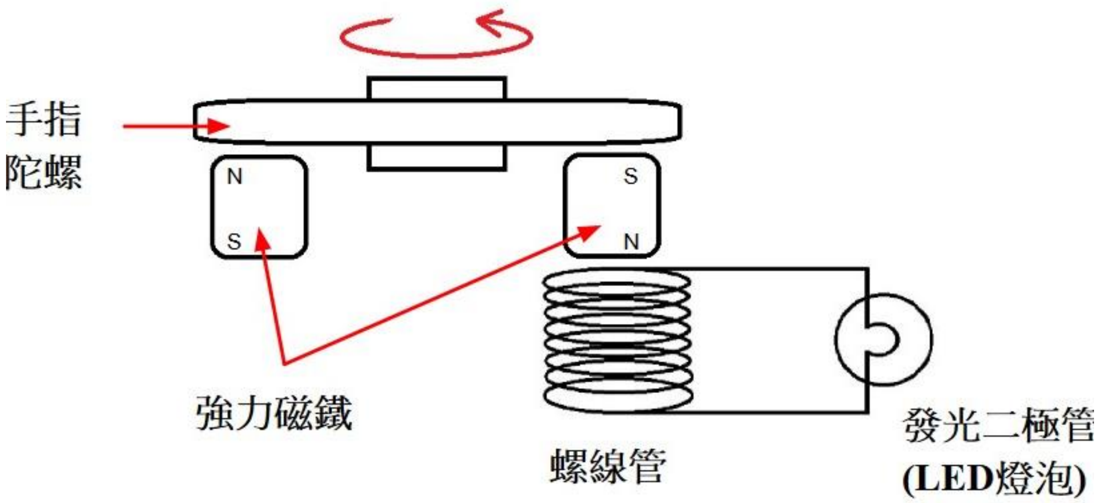
2. 為什麼陀螺在兩種金屬片上的轉動時間不同？

第二部份

實驗器材及裝置:



手指陀螺
強力磁鐵
螺線管
發光二極管（LED 燈泡）

實驗步驟:

1. 將三塊強力磁鐵固定於手指陀螺底部。
2. 啟動風筒推動陀螺加速轉動，觀察 LED 燈泡亮度的變化。
3. 關掉風筒，觀察陀螺減速轉動時 LED 燈泡亮度的變化。

假設

試推測陀螺開始轉動時的現象，並簡單解釋。

觀察

1. 當風筒推動陀螺加速轉動時，你有什麼觀察？

2. 現在關掉風筒。你有什麼觀察？

討論

請以法拉第定律解釋以下的現象：

1. 為什麼當陀螺加速轉動時，LED 燈泡的亮度會有所變化？

2. 為什麼當陀螺減速轉動時，LED 燈泡的亮度會有所變化？

延伸探究

1. 你會如何改善實驗裝置，使 LED 燈泡的亮度進一步提升？

Electromagnetic Induction
Fidget Spinner Experiment - Handout

Name:__________________( ) Class:________ Date:______________

Objective

- To visualise the effect of Lenz's Law and Faraday's Law
- To determine the factors that affect the magnitude of induced e.m.f. and current

Warm-up Questions

1. State Lenz's Law.

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2. How does the rate of change of magnetic flux through the coil affect the magnitude of the induced e.m.f.?

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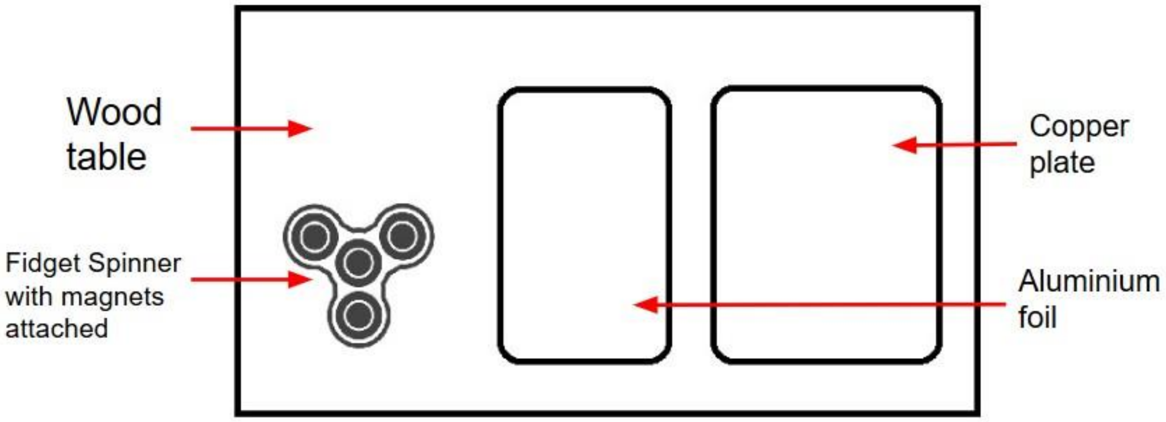
Part I
Experimental Set-up:



Experimental Procedures:

1. Attach three thin magnets to each arm of the fidget spinner.
2. Rotate the fidget spinner on the wood table. Record the rotation time.
3. Repeat step 2 on an aluminium foil and a copper plate.

Hypothesis
In which set-up (wood table/aluminium foil/copper plate) do you think the fidget spinner will spin for the shortest duration? Why?

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Observation
Record the rotation time of the spinner in the table below.

The surface below the spinner	Rotation time (s)		
	1	2	3
Wood table			
Aluminium foil			
Copper plate			

The surface with the shortest rotation time is: ________________________________

Explanation

1. Why will the spinner stop rotating sooner on the metal plates?
   (Hint: think about Lenz's Law)

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2. Why is the rotation time of the spinners on the two metal plates different?

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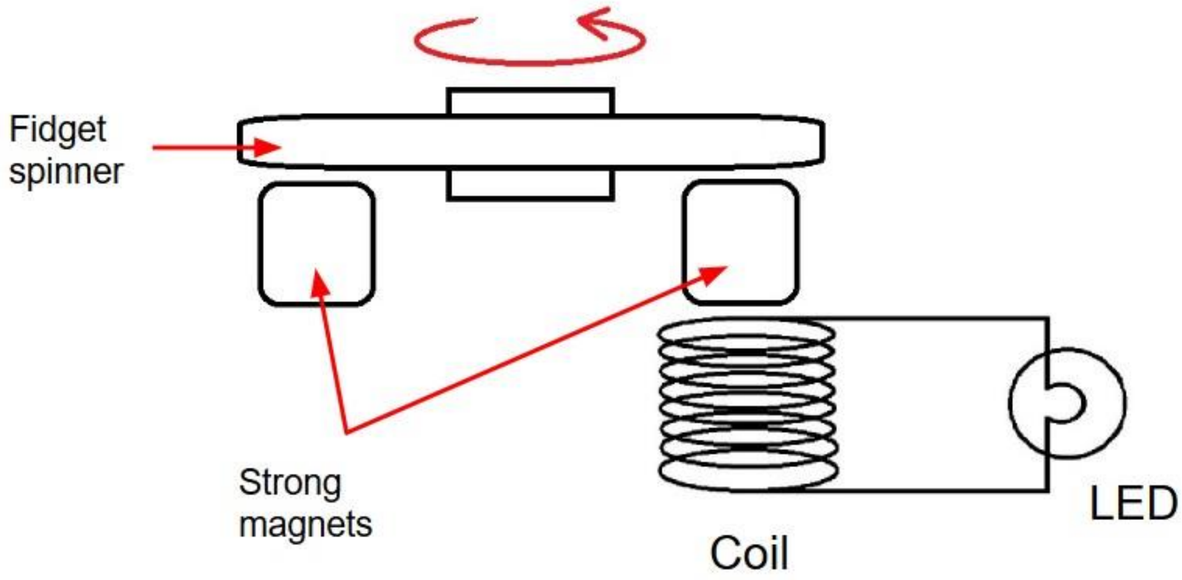
Part II

Experimental Set-up:



Experimental Procedures:

1. Attach three strong magnets onto each arm of the fidget spinner.
2. Use a hair dryer to accelerate the fidget spinner. Observe any changes in the brightness of the LED.
3. Turn off the hair dryer. Observe any changes in brightness when the spinner is decelerating.

Hypothesis

Predict what you will observe when the spinner starts to rotate with brief explanations.

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Observation

1. The spinner is accelerated by the hair dryer. What do you observe?

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2. Now the hair dryer is turned off. What do you observe?

____

____

Explanation

Refer to Faraday's Law, explain the following:

1. Why would the brightness of the LED change when the spinner is accelerating?

____

____

____

2. Why would the brightness of the LED change when the spinner is decelerating?

____

____

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Further Investigation

1. How can you improve the set-up to make the LED glows even brighter?

____

____

____

參考答案

熱身問題

1. 試寫出楞次定律。
- **感生電流**流動的**方向**總是在**抗衡**導致電流產生的**改變**。
2. 線圈中磁通量的改變速率如何影響感生電動勢的大小？
- 磁通量的**改變**速率**越快**，所產生的**感生電動勢越大**。

第一部分

觀察

在下面的表格中記錄陀螺完全停止轉動所需的時間。

- 任何根據以下次序的合理答案：**木桌（最長時間）＞鋁箔＞銅片（最短時間）**
- 陀螺在 **銅片** 上轉動的時間最短。

討論

1. 為什麼在金屬片上的陀螺會較早停止轉動？
- 當陀螺上的**磁鐵轉動**時，**磁通量**的**變化**產生了**感生電動勢**，使金屬片上出現了**感生電流**。根據楞次定律，感生電流流動的**方向**總是在**抗衡**導致電流產生的**改變**。因此，**感生電流所產生的磁力**能**抗衡陀螺的轉動**，令陀螺很快停止轉動。

2. 為什麼陀螺在兩種金屬片上的轉動時間不同？
- 因為**銅片的電阻率較鋁箔低**，根據**歐姆定律**（$V=IR$），一樣的感生電動勢在銅片上能產生**較大的感生電流**。因此，**感生電流產生更大的磁力抗衡在銅片上轉動的陀螺**，令陀螺**更快停止**轉動。

第二部分

觀察

1. 當風筒推動陀螺加速轉動時，你有什麼觀察？
- 當陀螺加速轉動時，LED 燈泡的**亮度增加**。
- 當陀螺加速轉動時，LED 燈泡**發出閃光的頻率增加**。

2. 現在關掉風筒。你有什麼觀察？
- 當陀螺減速轉動時，LED 燈泡的**亮度降低**。
- 當陀螺減速轉動時，LED 燈泡**發出閃光的頻率減低**。

討論

請以法拉第定律解釋以下的現象:

1. 為什麼當陀螺加速轉動時，LED 燈泡的亮度會有所變化？

當陀螺加速轉動時，**磁通量**的**變化率增加**（因為磁鐵在線圈中的移動的速度增加），產生了**較大**的**感生電動勢**。由於線圈和 LED 燈泡的電阻不變，經過 LED 燈泡的**電流增加**。因此，LED 燈泡的亮度增加。

2. 為什麼當陀螺減速轉動時，LED 燈泡的亮度會有所變化？

當陀螺減速轉動時，**磁通量**的**變化率減少**（因為磁鐵在線圈中的移動的速度減少），產生了**較小**的**感生電動勢**。由於線圈和 LED 燈泡的電阻不變，經過 LED 燈泡的**電流減少**。因此，LED 燈泡的亮度減少。

延伸探究

1. 你會如何改善實驗裝置，使 LED 燈泡的亮度進一步提升？

- 將更強的磁鐵固定於陀螺底部
- 增加螺線管線圈的圈數

Suggested answers

Warm-up Questions

1. Can you recall Lenz's Law?

- An **induced current** always flows in a **direction** to oppose the change that produces **the current**.

2. How will the magnitude of induced e.m.f. be affected by the rate of change of magnetic flux through the coil?

- The **larger the rate of change** of magnetic flux, the **larger the induced e.m.f.** in the coil.

Observation

Record the rotation time of the spinner in the table below.

- Reasonable answers following the order: **wood table (longest) > aluminium> copper plate (shortest)**
- The surface with the shortest rotation time is: **copper plate**

Explanation

1. Why will the spinner stop rotating sooner on the metal plates?

- When the **magnets** on the spinner **rotate**, there is a **change in the magnetic flux through the metal plates**, which **induces an e.m.f**. on the metal plate. According to Lenz's Law, when an induced current is formed, the induced current flows in a **direction that opposes the change (rotating magnets)** causing it. So the **rotational motion of the spinner is opposed** by the **magnetic force produced by induced current,** causing the spinner to stop rotating sooner.

2. Why are the rotation time of the spinner on the two metal plates different?

- As **copper has a lower resistivity than aluminium**, according to **Ohm's law** (*V*=*IR*), the same induced e.m.f. will produce a **larger induced current (eddy current)** in the copper plate. So the **rotational motion of the spinner is opposed to a larger extent** by a **larger magnetic force** on the copper plate, causing it to **stop rotating sooner**.

Part II

Observation

1. The spinner is accelerated by the hair dryer. What do you observe?

- The **brightness** of the LED **increases** when the spinner rotates with increasing speed.
- The LED **flashes more frequently** when the spinner rotates with increasing speed.

2. Now the hair dryer is turned off. What do you observe?

- The **brightness** of the LED **decreases** when the spinner rotates with decreasing speed.
- The LED **flashes less frequently** when the sspinner rotates with decreasing speed.

Explanation

With the aid of Faraday's Law, explain the following:

1. Why would the brightness of the LED increase when the spinner is accelerated?

When the rotational speed of the spinner increases, **the change in magnetic flux** (by the magnets attached) **per unit time increases** (as the magnets move faster towards and away from the coil. This generates a **greater induced emf.** As the resistance of the coil and the LED remains the same, the **current received by the LED increases**. Therefore the LED becomes brighter.

2. Why would the brightness of the LED decrease when the spinner is decelerated?

When the rotational speed of the spinner decreases, **the change in magnetic flux** (by the magnets attached) **per unit time decreases** (as the magnets move slower towards and away from the coil. This generates a **smaller induced emf.** As the resistance of the coil and the LED remains the same, the **current received by the LED decreases**. Therefore the LED becomes dimmer.

Further Investigation

1. How can you improve the set-up to make the LED glows even brighter?

- Attach stronger magnets to the fidget spinner.
- Increase the number of turns of the coil.

Visualizing Electromagnetism through Fidget Spinner

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