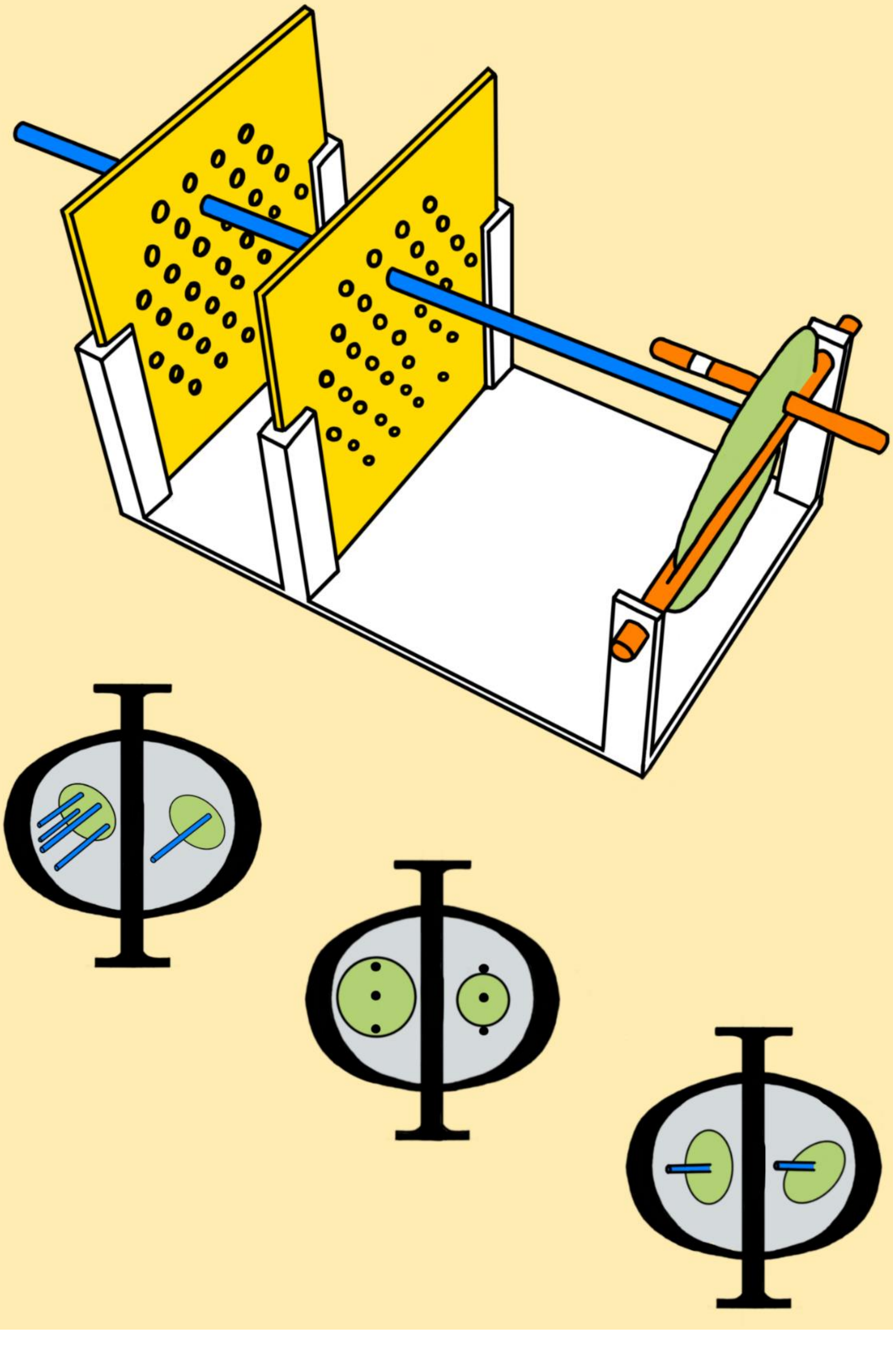
Dynamic Magnetic Flux Model

睇通「磁通量」



優質教育基金
Quality Education Fund

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

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The dynamic magnetic flux model

INTRODUCTION

An innovative 3D-printed teaching model that facilitates students' conceptual understanding of magnetic flux

OBJECTIVES

After the demonstrations, students are expected to

- state the mathematical definition of magnetic flux through an area $\Phi = BA \cos \theta$;
- explain how different quantities are related to the magnetic flux through an area

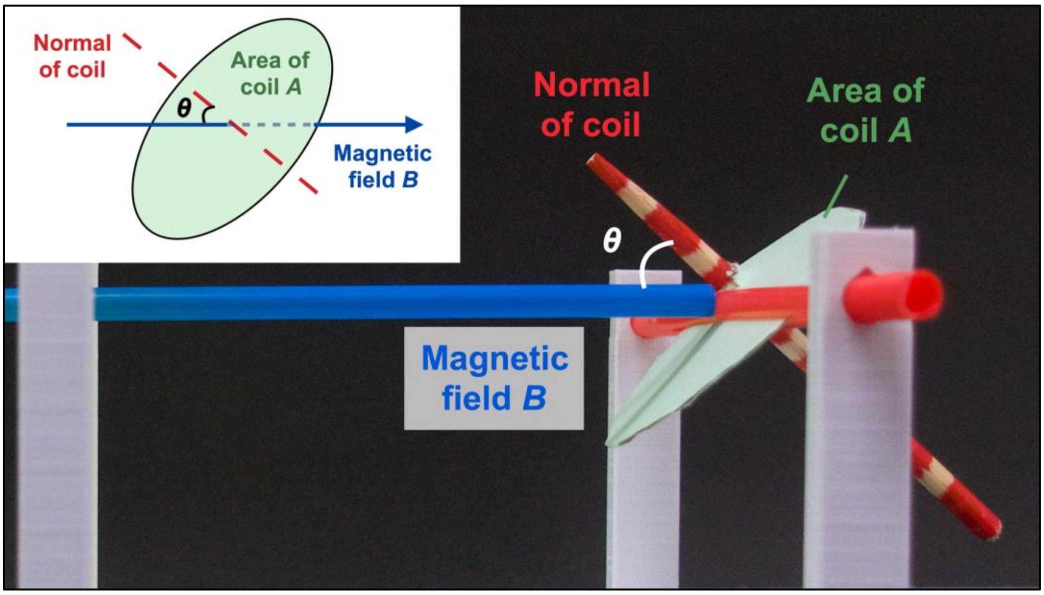


Fig. 1 The 3D Magnetic Flux model

MATERIALS

Item	Quantity
3D-printed base	1
3D-printed plate	2
Straw	7 – 12
Straw with a slit	1
Paper/Plastic cardboard (smaller)	1
Paper/Plastic cardboard (larger)	1
Coloured wooden stick	2

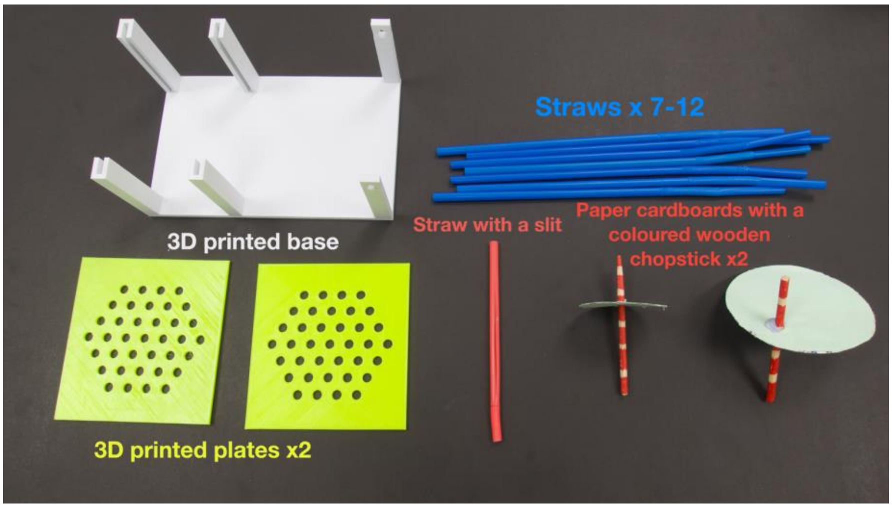


Fig. 2 Required materials of the model

PREPARATION AND DEMONSTRATION OF THE MODEL

Preparation

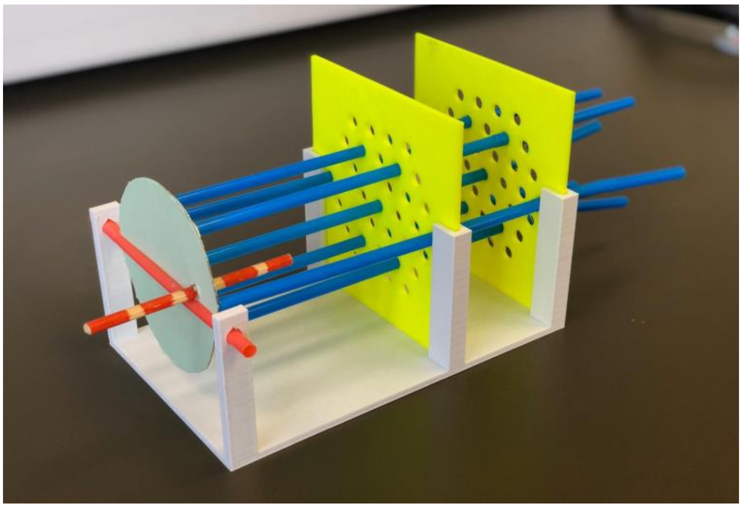
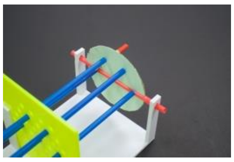
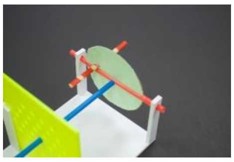
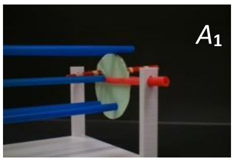
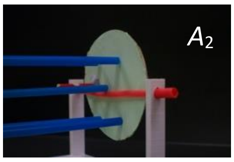
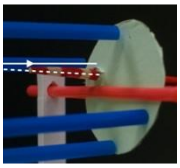
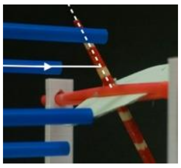
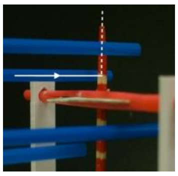


Fig. 3 The assembled 3D Magnetic Flux model

Demonstration

This model was designed to illustrate the factors related to magnetic flux: (i) the magnetic field strength (*B*), (ii) the area of the coil (*A*), and (iii) the angle between *B* and the normal of area (*θ*). The possible adjustments are summarized in the following table:

Factors affecting magnetic flux	**Represented by**	**Possible adjustment**
(i) Magnetic field strength (*B*)	Number of straws (per unit area) / Density of straws	<u>Adding/ removing the straw(s)</u> e.g. 4 straws vs. 1 straw  
(ii) Area of the coil (*A*)	Area of cardboard	<u>Changing the area of cardboard</u> e.g. $A_1 > A_2$  
(iii) Angle between *B* and the normal of the coil (*θ*)	The angle between the straws and the stick on the cardboard	<u>Rotating the cardboard</u> e.g. $\theta = 0°, \theta = 60°, \theta = 90°$  <u>θ = 0°</u>  <u>θ = 60°</u>  <u>θ = 90°</u>

LIMITATIONS OF THE MODEL

- The direction of magnetic field lines is not mentioned explicitly in the model.

SUGGESTED TEACHING PLAN

Name	**Key question of the lesson:** 1. What is magnetic flux?
School and Room	**Learning Objectives/ Intended Learning Outcomes:** ***Knowledge (Cognitive)*** K1. Define magnetic flux $\Phi = BA \cos \theta$ and Weber (Wb) as a unit of magnetic flux K2. Explain the change of magnetic flux with its related factors ***Skills (Psychomotor)*** S1. Demonstrate analytical skills of interpreting the magnetic flux parameters by using the magnetic flux model ***Values and attitude (Affective)***
Date and Time	
Subject Physics	
No. of students	
Form Secondary 5	
Topic Magnetic flux and flux density	
Characteristics of students Weak in visualizing concepts, especially in 3D With large learning diversity	

Topic taught last lesson:
- Lenz's law
- Fleming's right-hand rule

Students' relevant prior knowledge:
- Definition and graphic representation of magnetic field with field lines
- The density of magnetic field lines indicates the magnetic field strength

Set/Introduction (6 minutes)

<u>Assessment: Drawing the magnetic field pattern of a magnet</u>
1. Draw a bar magnet on the blackboard, invite students to draw its magnetic field lines
2. Invite other students to comment on the student's answer

<u>Assessment: The density of magnetic field lines indicates the magnetic field strength</u>

3. Draw two coils, one near and one far from the magnet. Ask the student which one experiences a larger magnetic field, and explain their answer
4. Following up on the students' response, the teacher mentions "higher density of field lines indicates stronger field strength"
5. Pose the question to the student: How to relate field lines and field strength mathematically?

Development (13 minutes)

Time (mins)	Teacher Activities (What teacher does) [including guiding questions]	Students Activities (What students do)	Remarks (e.g. AV aids, physical setting)	Obj. achieved
-	*Introducing magnetic flux and magnetic flux linkage.* ** Assume students have already learned the related theories*	*Listen to the teacher.*	*Blackboard, notes*	*K1*

3	Introduce the model, and guide students to relate the model with the theory just learned. **[Question]** How to relate the parts of the model with the theory of magnetic flux?	Observation, class sharing, listening and commenting on others' answers, Note-taking from the discussion.	Magnetic flux model, notes	K1, S1
	Invite a student to share his/her answer and ask other students to comment on the answer. The teacher explains the correct answer afterwards.			
10	**[Question]** What are the relationships between the magnetic flux Φ and the factors affecting it? Give some time for students to play with the model and discuss the answers. Invite students to share their answers followed by the teacher's elaboration.	Hands-on experience with the model. Recording findings on notes, class sharing. Photo-taking to record the observation by iPad.	Magnetic flux model, notes, iPad	K1, K2, S1
Conclusion (1 minute)				
Review the factors affecting the magnetic flux, and their relationship with it.				

磁通量模型

法拉第定律和磁通量

學習目標

- 定義磁通量 $\Phi = BA \cos \theta$
- 解釋磁場 B 為磁通量密度

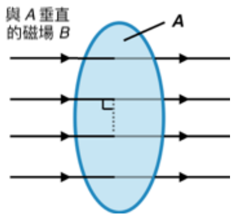
背景

A. 磁通量 (Φ)

- 用於量度通過某個面積的磁力線數量

情況 1：當磁場 B 垂直通過面積為 A 的一匝線圈時 ($\theta = 0°$)：

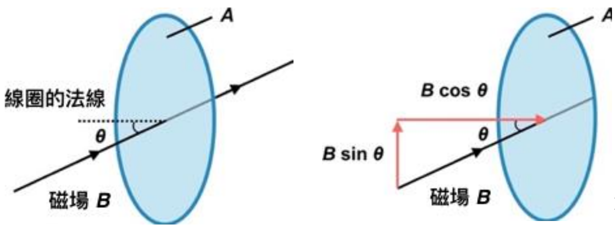
$$\Phi = BA$$



磁場 B 垂直通過面積為 A 的線圈

情況 2：當磁場 B以角度 θ 通過面積為 A 的一匝線圈時 ($0 < \theta < 90°$)：

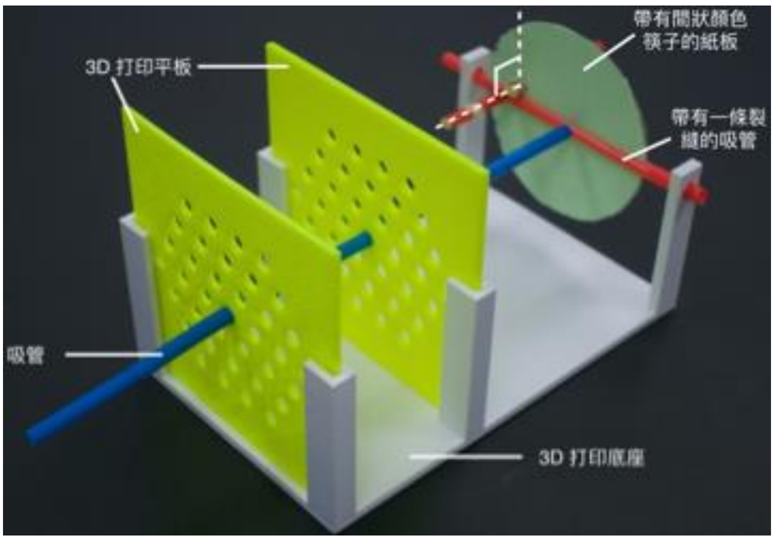
$$\Phi = BA \cos \theta$$



[1]

磁場 B 角度 θ 通過面積為 A 的一匝線圈時

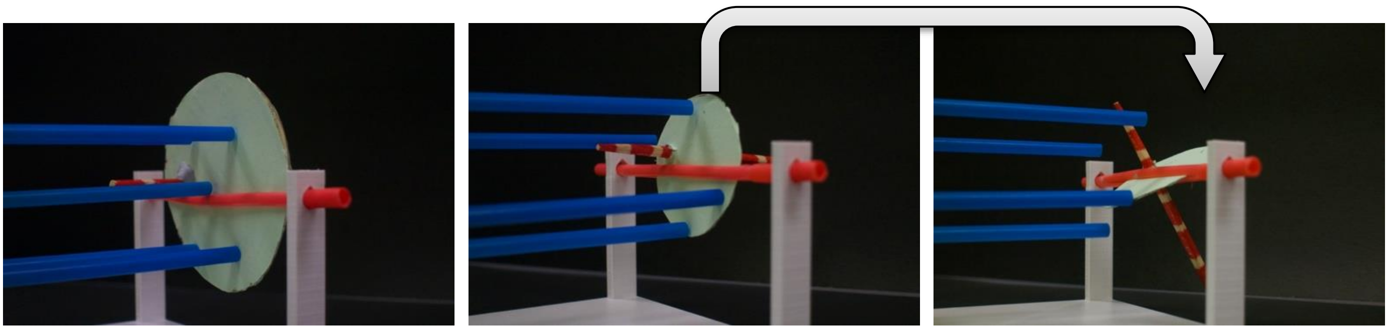
B. 模型圖



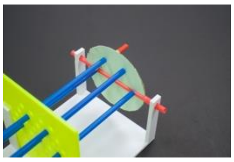
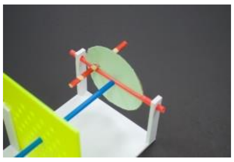
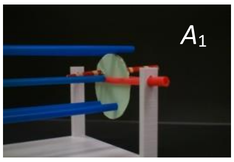
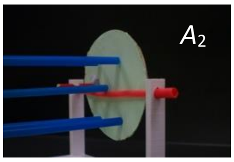
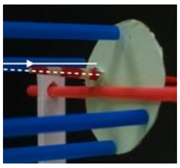
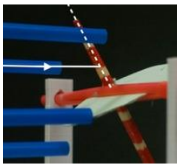
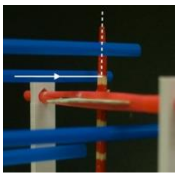
[1] 黃小玲，彭永聰，李浩然，林兆斌. (2015). 新高中生活與物理（第二版）.第四冊 電和磁. 香港： 牛津大學出版社（中國）有限公司. 第242頁.

活動

辨別改變磁通量的因素



「切過紙板的吸管的數量」實質上是表示什麼物理量？

<table>
<tr><th colspan="2">改變磁通量的因素</th><th colspan="2">能切過紙板的吸管數量的改變</th><th>此物理量與磁通量 Φ 的關係</th></tr>
<tr><td> 
（每單位面積）吸管數量/ 吸管密度
➩ 吸管數量由 7支 增至 10支</td><td>所表示的物理量：</td><td colspan="2"></td><td></td></tr>
<tr><td> 
紙板面積
➩ 換上一個較大面積的紙板 ($A_2 > A_1$)</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="3"> <u>$\theta = 0°$</u>
 <u>$\theta = 60°$</u>
 <u>$\theta = 90°$</u>
吸管與線圈的法線之夾角
➩ 把紙板由 0° 旋轉至 90°</td><td rowspan="3"></td><td>$\theta = 0°$</td><td></td><td rowspan="3"></td></tr>
<tr><td>$\theta = 60°$</td><td></td></tr>
<tr><td>$\theta = 90°$</td><td></td></tr>
</table>

練習

1) 一個一匝線圈放在磁通量密度為 1.5×10^{-3} T 的勻強磁場內，磁場與線圈互相垂直，線圈直徑為 5 cm。

   a. 求 通過線圈的磁通量，並列出步驟。

   b. 當磁通量密度由 1.5×10^{-3} T 增加至 5×10^{-3} T，
      i. 求 新的磁通量。
      ii. 求 在 (b)(i) 新舊磁通量的差。

   c. 當線圈直徑由 5 cm 縮小至 2 cm，
      i. 求 新的磁通量。
      ii. 求 在 (c)(i) 新舊磁通量的差。

   d. 當線圈在磁場內轉動 60°，
      i. 求 新的磁通量。
      ii. 求 在 (d)(i) 新舊磁通量的差。

   e. 當題 (b)、題(c) 、題(d) 的轉變同時發生，
      i. 求 新的磁通量。
      ii. 求 在 (e)(i) 新舊磁通量的差。

Magnetic Flux Model

Faraday's Law and Magnetic Flux

Objective

- To define magnetic flux $\Phi = BA \cos \theta$
- To interpret magnetic field B as magnetic flux density

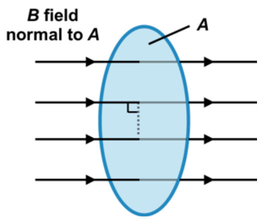
Background

A. Magnetic flux (Φ)

- Magnetic flux: A measure of the amount of magnetic field lines cutting through an area.

Case 1) When a magnetic field B *passes through a single coil normally* with an area A ($\theta = 0°$):

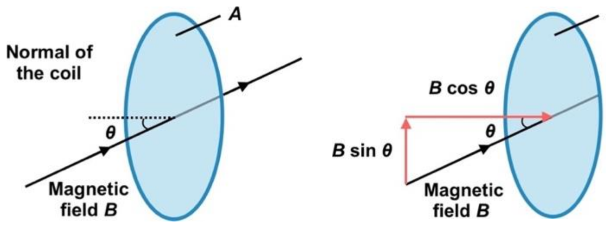
$$\Phi = BA$$



A magnetic field B is perpendicular to the coil

Case 2) When the magnetic field B *passes through a coil with an area A at an angle* θ ($0° < \theta < 90°$):

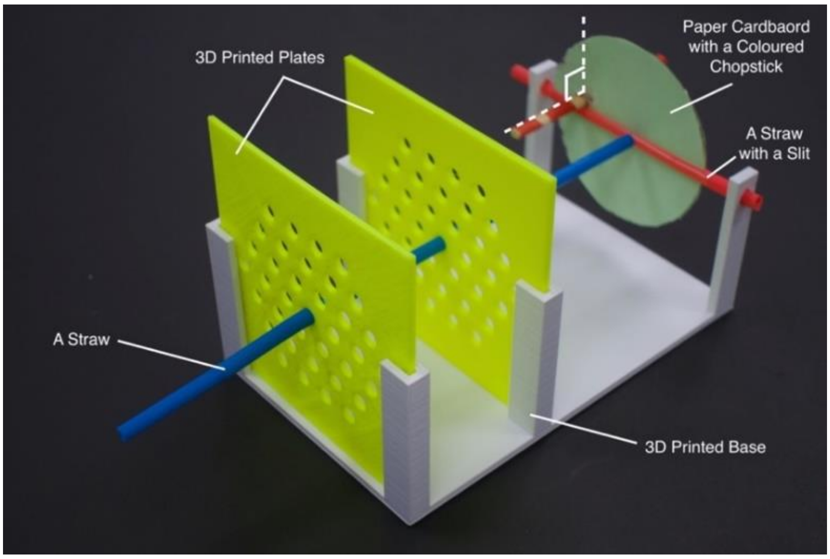
$$\Phi = BA \cos \theta$$



[2]

The magnetic field B passes through a coil with an area A at an angle θ

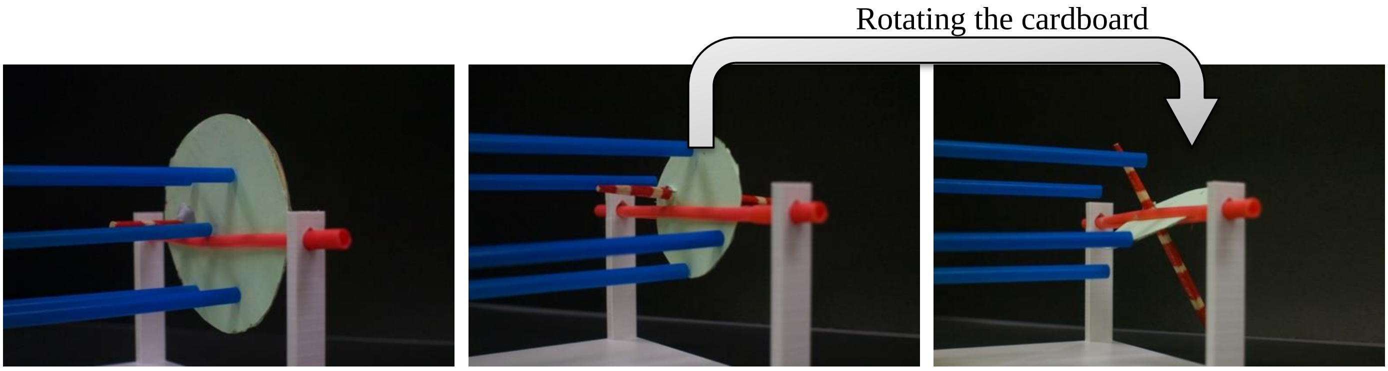
B. Illustration of the model



[2] Wong, S., Pang, W., Lie, H., & Lam, S. (2015). New senior secondary physics at work (Second ed.). Bk. 4 Electricity and Magnetism. Hong Kong: Oxford University Press (China) Limited. Page 242

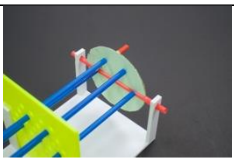
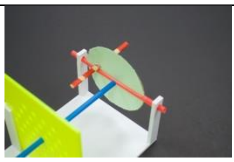
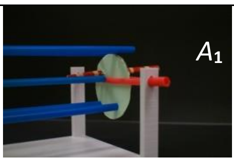
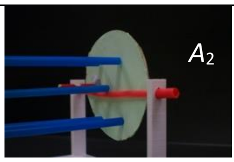
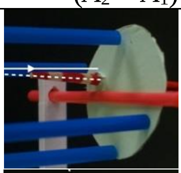
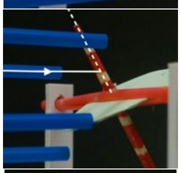
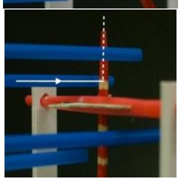
Activity

Identifying the change of magnetic flux with its related factors



What is the physical quantity represented by “the number of straws passing through the cardboard”?

____

<table>
<tr><th colspan="2">Factors affecting magnetic flux</th><th colspan="2">Number of straws cutting through the paper cardboard</th><th>Relationship between the factor and magnetic flux Φ</th></tr>
<tr><td> 
Number of straws (per unit area) / density of straws
⇨ Increasing the number of straws from 7 to 10</td><td>Physical quantities represented by the change</td><td colspan="2"></td><td></td></tr>
<tr><td> 
Area of cardboard
⇨ Using larger paper cardboard ($A_2 > A_1$)</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="3"> $\theta \approx 0°$
 $\theta \approx 60°$
 $\theta \approx 90°$
The angle between the straws and the normal of the coil
⇨ Rotate the paper cardboard from 0° to 90°</td><td rowspan="3"></td><td>$\theta \approx 0°$</td><td></td><td rowspan="3"></td></tr>
<tr><td>$\theta \approx 60°$</td><td></td></tr>
<tr><td>$\theta \approx 90°$</td><td></td></tr>
</table>

Practice

1) Consider a single-turn circular coil with a diameter of 5 cm.
   The coil is placed in a uniform magnetic field of 1.5×10^{-3} T, perpendicular to the magnetic field.

   a) What is the magnetic flux through the coil? Show the calculation.

   b) When the magnetic field increases from 1.5×10^{-3} T to 5×10^{-3} T,
      i. What is the new magnetic flux through the coil?
      ii. What is the change of the magnetic flux through the coil in (b)(i)?

   c) When the diameter decreases from 5 cm to 2 cm,
      i. What is the new magnetic flux through the coil?
      ii. What is the change of the magnetic flux through the coil in (c)(i)?

   d) When the coil is rotated 60° from the normal,
      i. What is the new magnetic flux through the coil?
      ii. What is the change of the magnetic flux through the coil in (d)(i)?

   e) When the changes to the setup in (b), (c) and (d) happen simultaneously,
      i. What is the new magnetic flux through the coil?
      ii. What is the change of the magnetic flux through the coil in (e)(i)?

磁通量模型

法拉第定律和磁通量

學習目標

- 定義磁通量 $\Phi = BA\cos\theta$
- 解釋磁場 B 為磁通量密度

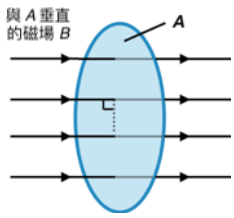
背景

A. 磁通量 (Φ)

- 用於量度通過某個面積的磁力線數量

情況 1：當磁場 B 垂直通過面積為 A 的一匝線圈時 ($\theta = 0°$)：

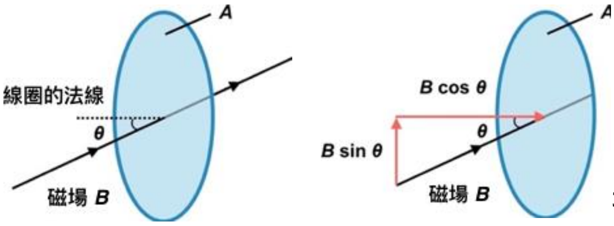
$$\Phi = BA$$



磁場 B 垂直通過面積為 A 的線圈

情況 2：當磁場 B以角度 θ 通過面積為 A 的一匝線圈時 ($0 < \theta < 90°$)：

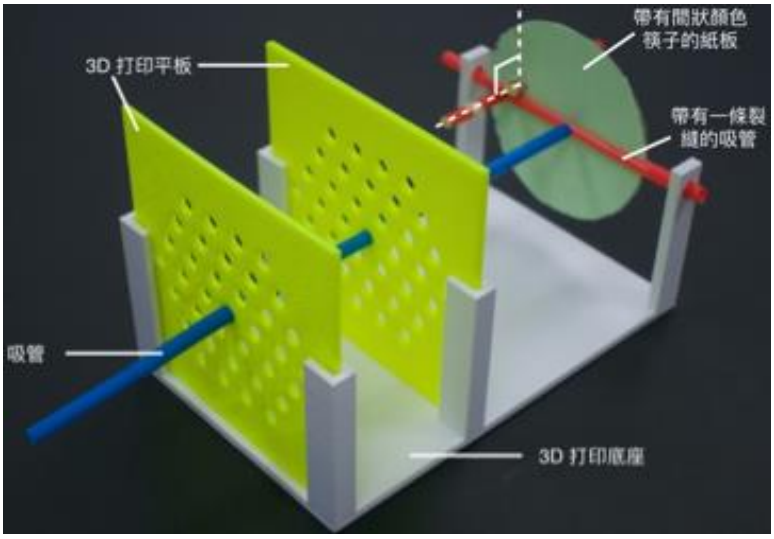
$$\Phi = BA\cos\theta$$



[3]

磁場 B 角度 θ 通過面積為 A 的一匝線圈時

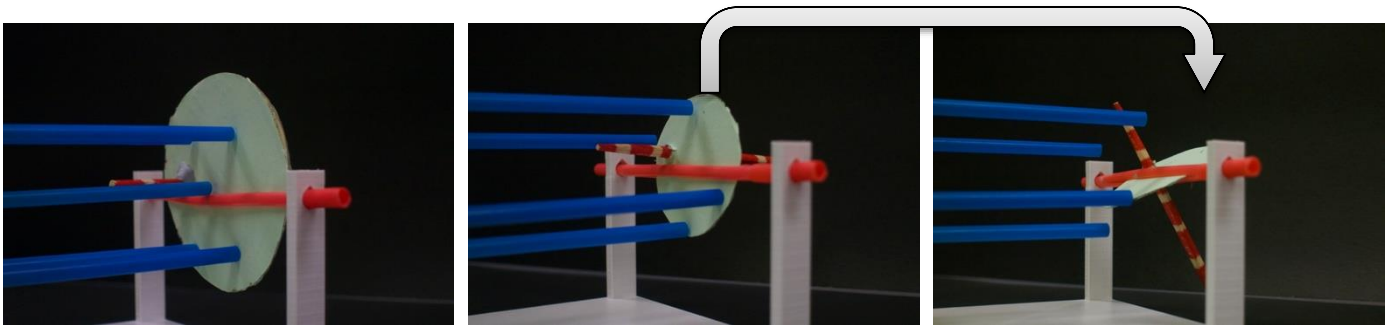
B. 模型圖



[3] 黃小玲，彭永聰，李浩然，林兆斌. (2015). 新高中生活與物理（第二版）.第四冊 電和磁. 香港： 牛津大學出版社（中國）有限公司. 第242頁.

活動

辨別改變磁通量的因素



「切過紙板的吸管的數量」實質上是表示什麼物理量？

磁通量 Φ

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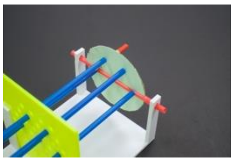
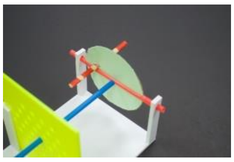
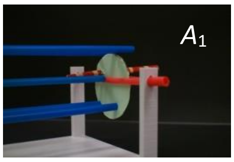
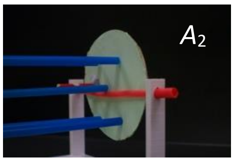
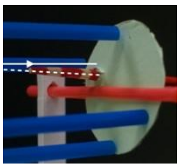
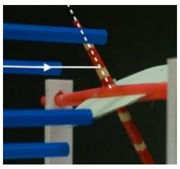
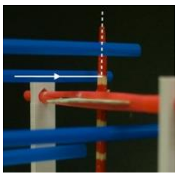
<tr><td> 
（每單位面積）吸管數量/ 吸管密度
➪ 吸管數量由 7支 增至 10支</td><td>所表示的物理量：
磁場強度 B</td><td colspan="2">當吸管數量增加時，能切過紙板的吸管數量會因而增加</td><td>$\Phi \propto B$
當磁場強度增加時，磁通量會因而增加</td></tr>
<tr><td> 
紙板面積
➪ 換上一個較大面積的紙板 ($A_2 > A_1$)</td><td>紙板面積 A</td><td colspan="2">當紙板面積增加時，能切過紙板的吸管數量會因而增加</td><td>$\Phi \propto A$
當線圈面積增加時，磁通量會因而增加</td></tr>
<tr><td rowspan="3"> $\theta = 0°$
 $\theta = 60°$
 $\theta = 90°$
吸管與線圈的法線之夾角
➪ 把紙板由 0° 旋轉至 90°</td><td rowspan="3">磁場和線圈法線的夾角 θ</td><td>$\theta \approx 0°$</td><td>很多吸管能切過紙板</td><td rowspan="3">$\Phi \propto \cos\theta$
當磁場和線圈法線的夾角減少時，磁通量會因而增加</td></tr>
<tr><td>$\theta \approx 60°$</td><td>部分吸管能切過紙板</td></tr>
<tr><td>$\theta \approx 90°$</td><td>沒有吸管能切過紙板</td></tr>
</table>

練習

2) 一個一匝線圈放在磁通量密度為 1.5×10^{-3} T 的勻強磁場內，磁場與線圈互相垂直，線圈直徑為 5 cm。

   a. 求 通過線圈的磁通量，並列出步驟。

   磁通量 $\Phi = BA\cos\theta = (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$

   $= 2.95 \times 10^{-6}$ Wb

   b. 當磁通量密度由 1.5×10^{-3} T 增加至 5×10^{-3} T，

      i. 求 新的磁通量。

      ii. 求 在 (b)(i) 新舊磁通量的差。

   i. 磁通量 $\Phi = BA\cos\theta = (5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$

   $= 9.82 \times 10^{-6}$ Wb

   ii. 新舊磁通量的差

   $= (5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$

   $= 6.87 \times 10^{-6}$ Wb

   c. 當線圈直徑由 5 cm 縮小至 2 cm，

      i. 求 新的磁通量。

      ii. 求 在 (c)(i) 新舊磁通量的差。

   i. 磁通量 $\Phi = BA\cos\theta = (1.5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2]\cos 0°$

   $= 4.71 \times 10^{-7}$ Wb

   ii. 新舊磁通量的差

   $= (1.5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2]\cos 0° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$

   $= -2.47 \times 10^{-6}$ Wb

   d. 當線圈在磁場內轉動 60°，

      i. 求 新的磁通量。

      ii. 求 在 (d)(i) 新舊磁通量的差。

   i. 磁通量 $\Phi = BA\cos\theta = (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 60°$

   $= 1.47 \times 10^{-6}$ Wb

   ii. 新舊磁通量的差

   $= (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 60° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$

   $= -1.47 \times 10^{-6}$ Wb

   e. 當題 (b)、題(c) 、題(d) 的轉變同時發生，

      i. 求 新的磁通量。

      ii. 求 在 (e)(i) 新舊磁通量的差。

   i. 磁通量 $\Phi = BA\cos\theta = (5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2]\cos 60°$

   $= 7.85 \times 10^{-7}$ Wb

   ii. 新舊磁通量的差

   $= (5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2)]\cos 60° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$

   $= -2.16 \times 10^{-6}$ Wb

Magnetic Flux Model

Faraday's Law and Magnetic Flux

Objective

- To define magnetic flux $\Phi = BA \cos \theta$
- To interpret magnetic field B as magnetic flux density

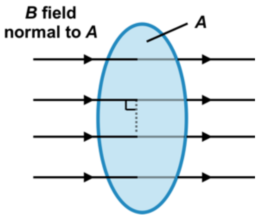
Background

C. Magnetic flux (Φ)

- Magnetic flux: A measure of the amount of magnetic field lines cutting through an area.

Case 1) When a magnetic field B *passes through a single coil normally* with an area A ($\theta = 0°$):

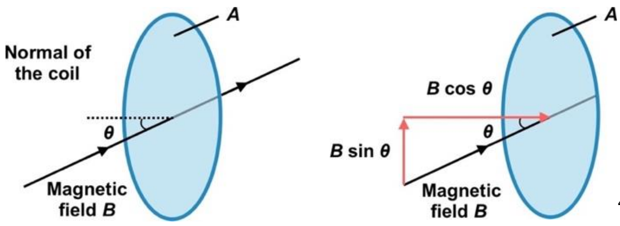
$$\Phi = BA$$



A magnetic field B is perpendicular to the coil

Case 2) When the magnetic field B *passes through a coil with an area A at an angle* θ ($0° < \theta < 90°$):

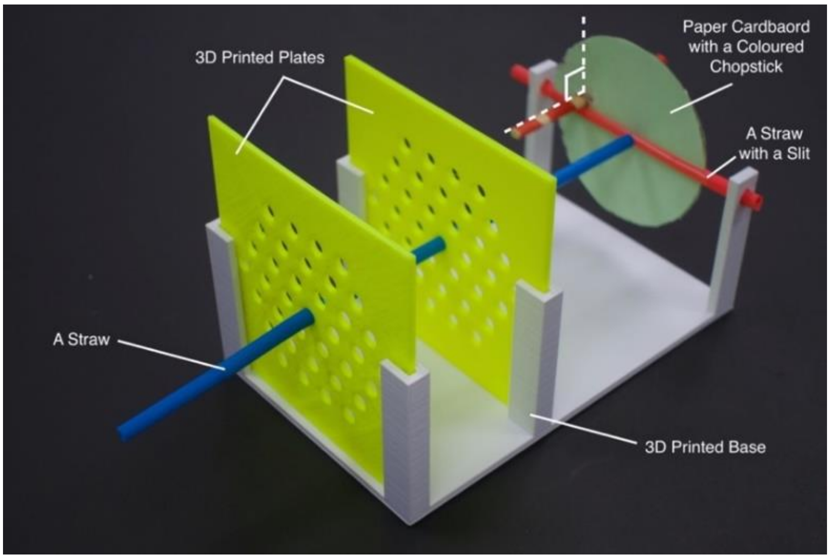
$$\Phi = BA \cos \theta$$



[4]

The magnetic field B passes through a coil with an area A at an angle θ

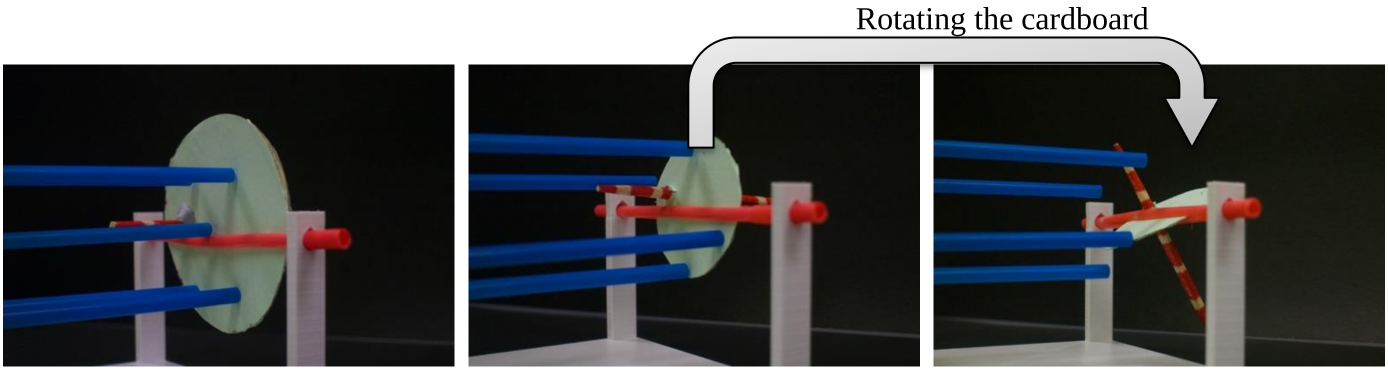
D. Illustration of the model



[4] Wong, S., Pang, W., Lie, H., & Lam, S. (2015). New senior secondary physics at work (Second ed.). Bk. 4 Electricity and Magnetism. Hong Kong: Oxford University Press (China) Limited. Page 242

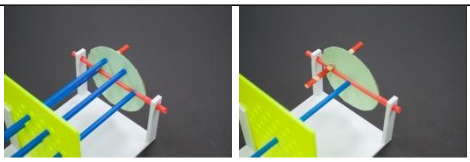
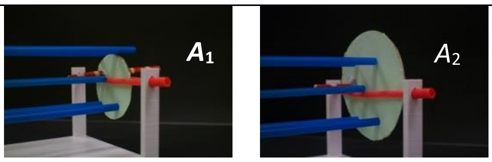
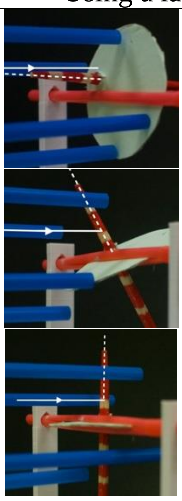
Activity

Identifying the change of magnetic flux with its related factors



What is the physical quantity represented by "the number of straws passing through the cardboard"?

Magnetic flux Φ

Factors affecting magnetic flux		**Number of straws cutting through the paper cardboard**	**Relationship between the factor and magnetic flux Φ**
 Number of straws (per unit area) / density of straws ⇨ Increasing the number of straws from 7 to 10	Physical quantities represented by the change Magnetic field strength *B*	The number of straws cutting through the paper cardboard increases as the number of straws increases	$\Phi \propto B$ The magnetic flux increases as the magnetic field strength increases.
 Area of cardboard ⇨ Using a larger paper cardboard ($A_2 > A_1$)	Area of the coil *A*	The number of straws cutting through the paper cardboard increases as the area of cardboard increases	$\Phi \propto A$ The magnetic flux increases as the area of the coil increases.
 $\theta \approx 0°$ $\theta \approx 60°$ $\theta \approx 90°$ Angle between the straws and the normal of the coil ⇨ Rotate the paper cardboard from 0° to 90°	Angle between *B* and the normal of the coil θ	$\theta \approx 0°$: Many straws cutting through the cardboard $\theta \approx 60°$: Some straws cutting through the cardboard $\theta \approx 90°$: No straws cutting through the cardboard	$\Phi \propto \cos\theta$ The magnetic flux increases as the angle between *B* and the normal of the coil decreases.

Practice

1) Consider a single-turn circular coil with diameter 5 cm.
The coil is placed in a uniform magnetic field 1.5×10^{-3} T, perpendicular to the magnetic field.

a) What is the magnetic flux through the coil? Show the calculation.

Magnetic Flux $\Phi = BA\cos\theta = (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$
$= 2.95 \times 10^{-6}$ Wb

b) When the magnetic field increases from 1.5×10^{-3} T to 5×10^{-3} T,

i. What is the new magnetic flux through the coil?

ii. What is the change of the magnetic flux through the coil in (b)(i)?

i. Magnetic Flux $\Phi = BA\cos\theta = (5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$
$= 9.82 \times 10^{-6}$ Wb

ii. The Change of Magnetic Flux
$= (5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$
$= 6.87 \times 10^{-6}$ Wb

c) When the diameter decreases from 5 cm to 2 cm,

i. What is the new magnetic flux through the coil?

ii. What is the change of the magnetic flux through the coil in (c)(i)?

i. Magnetic Flux $\Phi = BA\cos\theta = (1.5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2]\cos 0°$
$= 4.71 \times 10^{-7}$ Wb

ii. The Change of Magnetic Flux
$= (1.5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2]\cos 0° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$
$= -2.47 \times 10^{-6}$ Wb

d) When the coil is rotated 60° from the normal,

i. What is the new magnetic flux through the coil?

ii. What is the change of the magnetic flux through the coil in (d)(i)?

i. Magnetic Flux $\Phi = BA\cos\theta = (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 60°$
$= 1.47 \times 10^{-6}$ Wb

ii. The Change of Magnetic Flux
$= (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 60° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$
$= -1.47 \times 10^{-6}$ Wb

e) When the changes to the setup in (b), (c) and (d) happen simultaneously,

i. What is the new magnetic flux through the coil?

ii. What is the change of the magnetic flux through the coil in (e)(i)?

i. Magnetic Flux $\Phi = BA\cos\theta = (5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2]\cos 60°$
$= 7.85 \times 10^{-7}$ Wb

ii. The Change of Magnetic Flux
$= (5 \times 10^{-3})\,[\pi\,(\frac{0.02}{2})^2)]\cos 60° - (1.5 \times 10^{-3})\,[\pi\,(\frac{0.05}{2})^2]\cos 0°$
$= -2.16 \times 10^{-6}$ Wb

Dynamic Magnetic Flux Model

睇通「磁通量」

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