Maxwell's Equations

Governing Rules Series

Instructor's Guide

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Developed by the Teaching and Learning Laboratory at MIT
for the Singapore University of Technology and Design

Introduction

When to Use this Video

- In Phys 201, after Lecture 35 or as a review for the final exam. This video is ideal for use in a discussion section, but might also be assigned for homework if students have the opportunity to work together.
- Prior Knowledge: Students must be familiar with all of Maxwell's Equations (in either integral or differential form), the existence of electromagnetic waves, and the Lorentz Force Law.

Key Information

Duration: 14:16
Narrator: Prof. Steven Leeb
Materials Needed:
• Paper
• Pencil/Pen

Learning Objectives

After watching this video students will be able to:

- Describe events and devices in terms of Maxwell's Equations.
- Decide which equation relates to which phenomena.

Motivation

- Most videos on Maxwell's Equations are either highly technical and mathematical, or purely conceptual at a very introductory level. This video seeks to find a middle ground, where the concepts can be applied rigorously without the need for calculation.
- Many students have difficulty applying Maxwell's Equations because they are uncertain where they apply, or whether they are appropriate to use in a given context. This video helps to contextualize the laws in a less abstract setting.

Student Experience

It is highly recommended that the video is paused when prompted so that students are able to attempt the activities on their own and then check their solutions against the video.

During the video, students will brainstorm ways in which Maxwell's Equations might apply to a particular concept.

Video Highlights

This table outlines a collection of activities and important ideas from the video.

Time	Feature	Comments
01:39	Brief description of AM broadcasting process	
03:15	Students brainstorm how to apply Maxwell's Equations to AM radio	
04:28	AM Radio described in detail	This segment is the majority of the video, and runs until the review at 13:41. The focus is on examining how Maxwell's Equations apply.
04:38	Gauss' Law applied to the transmitter	
05:28	Ampere's Law applied to the transmitter	
05:55	Gauss' Law for Magnetism applied to the transmitter	
06:18	Ampere-Maxwell Law applied to the propagation of radio waves	
06:40	Faraday's Law applied to the propagation of radio waves and their detection via the antenna	
07:45	Speaker demonstration – Lorentz Force Law	
11:53	Handmade speaker demonstration	
13:02	Review	
13:30	Return to brainstorms and re-examine	

Video Summary

This video uses the context of AM radio broadcasting to investigate the many applications of Maxwell's Equations. Students brainstorm a list about this topic at the beginning, and compare it to the items that are described as the video progresses.

Phys 201 Materials

Pre-Video Materials

When appropriate, this guide is accompanied by additional materials to aid in the delivery of some of the following activities and discussions.

1. Flux (Appendix A1-1 and A1-2)

These two questions are designed as a pair. One deals with a closed surface, the other with an open surface. In both cases the field lines pass through a flat, tilted surface. The questions should be used back-to-back, without time for discussion after the first one. Some students may want to re-vote on the first question after seeing the second question; this is recommended.

If students choose #5, it is important to probe for why that response was chosen. Students may choose this response when what they really mean is "I can't answer this question" or "None of the above are correct." Answer #5 should only be chosen by those who believe that the problem is genuinely unanswerable.

2. Elastic Loop (Appendix A2)

This situation is typically viewed from two different perspectives. The first is a Lenz's Law approach in which the situation adapts to maintain the same flux through the loop. The second is a combination of Faraday's Law and the Loretnz Force Law. This approach considers the electric field induced in the loop, which creates a current flow, which is acted on by the magnetic field. Both approaches yield the same answer.

3. Circulation (Appendix A3)

This problem is a straightforward application of Ampere's Law. It is intended as a concept check, and can be used to probe for students' basic familiarity and comfort with that law. This is an excellent opportunity to have students discuss the answer with each other after voting. The application of the law is fairly simple, and students who have the answer right for the right reason should be able to convince others with little difficulty.

4. Magnetic Field (Appendix A4)

This problem tests students' comfort with Gauss' Law for Magnetism. The most defensible answer is #4. Some students may state that there could be an associated south pole at a great distance from the north pole shown, or that the north is viewed at such an angle that the south is invisible. Encourage them not to view this as a "trick question."

Choice #5 is included so that you can set a standard in your classroom. Some students may have been taught to draw field lines with arrows, some may have been taught to avoid them. Neither approach is generally considered "wrong," but some instructors prefer one approach or another.

Post-Video Materials

1. Electromagnetism Worksheet (Appendix A5)

This worksheet gives a set of scenarios in which one or more of Maxwell's Equations is pertinent, and asks students to identify the law at work. It is recommended to use this as a short group activity for discussion sections. However, depending on the amount of time available in your classroom, you may want to assign this as part of homework, or require varying amounts of writing to accompany and explain the students' answers. The text of the worksheet is copied below.

For each item below, decide which of Maxwell's Equations (or the Lorentz Force Law) is responsible for the phenomenon described.

- When a magnet is dropped through a copper tube, the magnet falls more slowly than it would through a plastic tube of the same diameter.
- A magnet passing through a coil of wire will cause an electric current to flow through that wire.
- Discharging a capacitor creates a magnetic field in the region between the plates.
- A charged sphere can be treated as being concentrated at its center.
- The Auroras happen near the north and south poles.
- An aluminum plate that passes into or out of a region of strong magnetic field will feel a force against its direction of motion.
- The electrical resistance is higher in a wire where the current flows perpendicularly to a strong magnetic field.

Additional Resources

Going Further

In the Going Further folder is a set of step-by-step instructions for creating a hand-built speaker similar to the one seen in the video.

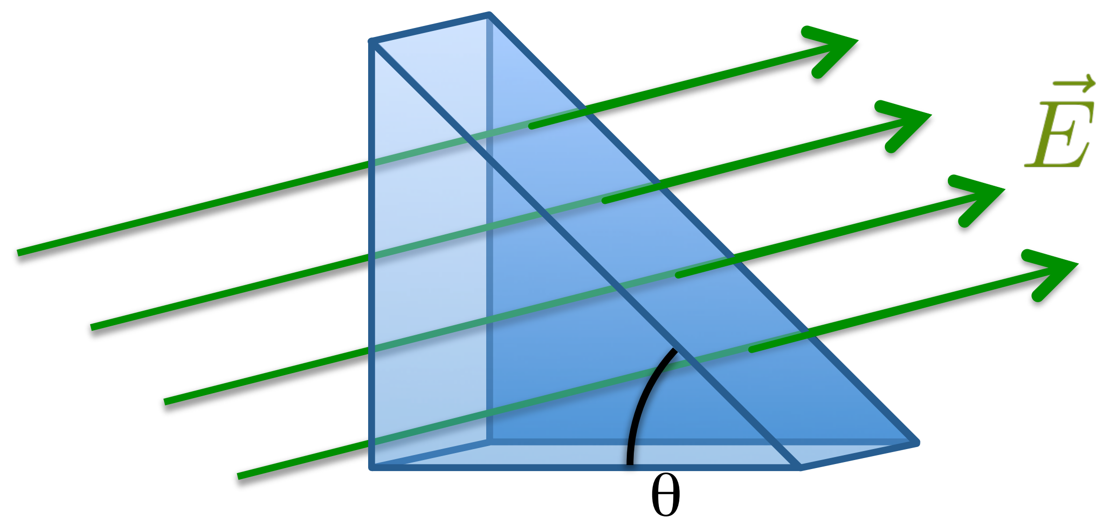
As with all engineering projects, this one requires some amount of fine-tuning and "tweaking" after it is built in order to make it function optimally. The strength of the signal source, the stiffness of the springs, the weight of the components, the strength of the magnet, and more can all contribute to how well the speaker functions.

References

Three fairly broad studies of student understanding in electromagnetism are included below. The fourth reference is more narrowly focused on Ampère's Law, but its conclusions have the potential to be generalized to other laws as well.

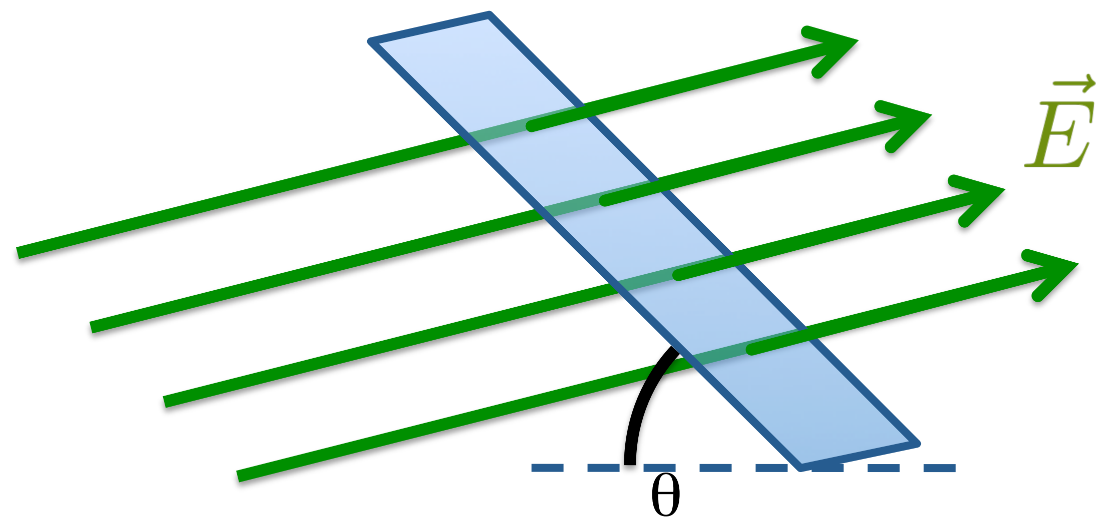
- Ferguson-Hessler, M., & Jong, T. (1987). On the quality of knowledge in the field of electricity and magnetism. *American Journal of Physics, 55*(6), 492-497.
- Maloney, D., O'Kuma, T., Hieggelke, C., & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics, 69*(S1), S12-23.
- Sağlam, M & Millar, R. (2006). Upper High School Students' Understanding of Electromagnetism, *International Journal of Science Education, 28*(5), 543-566
- Manogue, C., Kerry Browne, K., Dray, T., Edwards, B. (2006). Why is Ampère's law so hard? A look at middle-division physics. *American Journal of Physics, 74*(4), 344-350.

Using the situation illustrated below, how would you increase the electric flux through this closed surface? Choose all answers that apply.

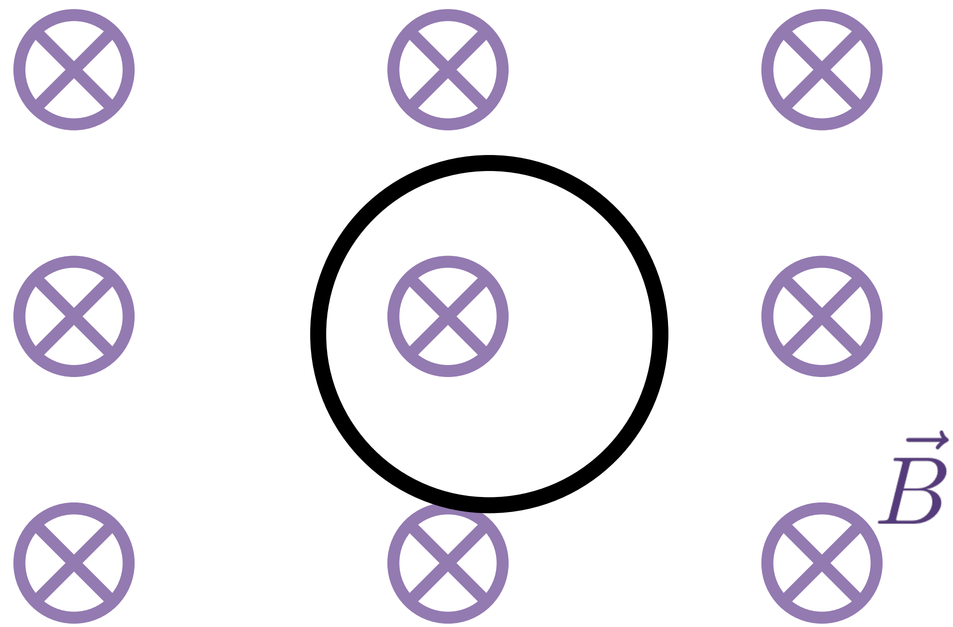


1. Increase θ
2. Decrease θ
3. Increase the strength of the electric field
4. Make the surface larger in all directions
5. This question is impossible to answer

Using the situation illustrated below, how would you increase the electric flux through this open surface? Choose all answers that apply.



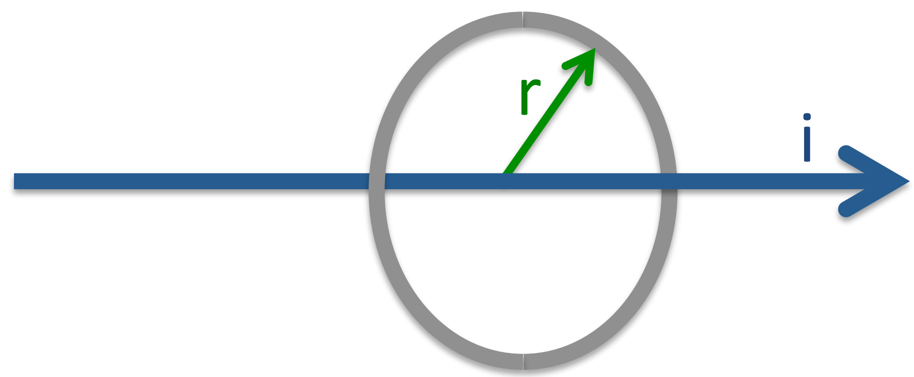
① Increase θ
② Decrease θ
③ Increase the strength of the electric field
④ Make the surface larger in all directions
⑤ This question is impossible to answer



A magnetic field is shown above, with a conducting loop inside. The loop is elastic, able to expand or shrink. If the magnetic field increases with time, the loop will…

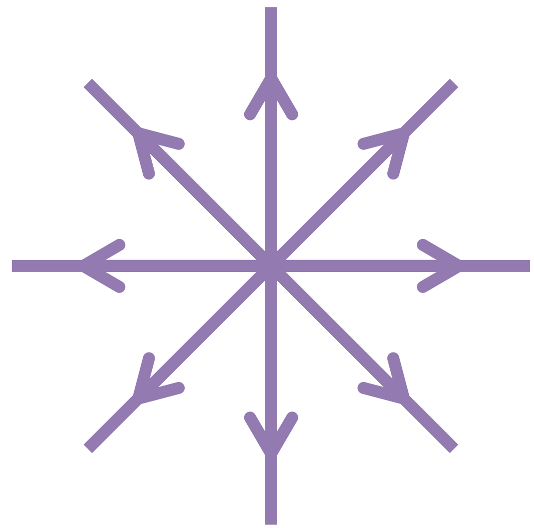
① Expand
② Shrink
③ Remain the same size
④ Impossible to say

An Amperian loop of radius r is drawn around a wire that carries current i as shown. Which combinations of radius and current described below yield the largest value for $\oint \vec{B} \cdot d\vec{s}$ around the loop?



1. i = 10A, r = 1m
2. i = 10A, r = 2m
3. i = 10A, r = 4m
4. i = 5A, r = 1m
5. i = 5A, r = 2m
6. i = 5A, r = 4m
7. All choices yield the same value.

The image shown below is an unacceptable depiction of magnetic field lines. Why? Choose all that apply.



① Incorrect; this is actually an acceptable depiction of magnetic field lines.
② The magnetic field lines do not curve.
③ The field lines are pointing in the wrong direction.
④ Only a single magnetic pole is depicted.
⑤ Arrows are not drawn along field lines.

Electromagnetism Worksheet

For each item below, decide which of Maxwell's Equations (or the Lorentz Force Law) is responsible for the phenomenon described.

1. When a magnet is dropped through a copper tube, the magnet falls more slowly than it would through a plastic tube of the same diameter.
2. A magnet passing through a coil of wire will cause an electric current to flow through that wire.
3. Discharging a capacitor creates a magnetic field in the region between the plates.
4. A charged sphere can be treated as being concentrated at its center.
5. The Auroras happen near the north and south poles.
6. An aluminum plate that passes into or out of a region of strong magnetic field will feel a force against its direction of motion.
7. The electrical resistance is higher in a wire where the current flows perpendicularly to a strong magnetic field.