Magnetic Induction

I. Induction
   - Faraday's Law, Lenz's Law

II. Maxwell's equations

III. Inductance and Inductors
   - design and geometry

IV. RL Circuits
   - steady state, dynamic behavior

V. LC Circuits
   - oscillations

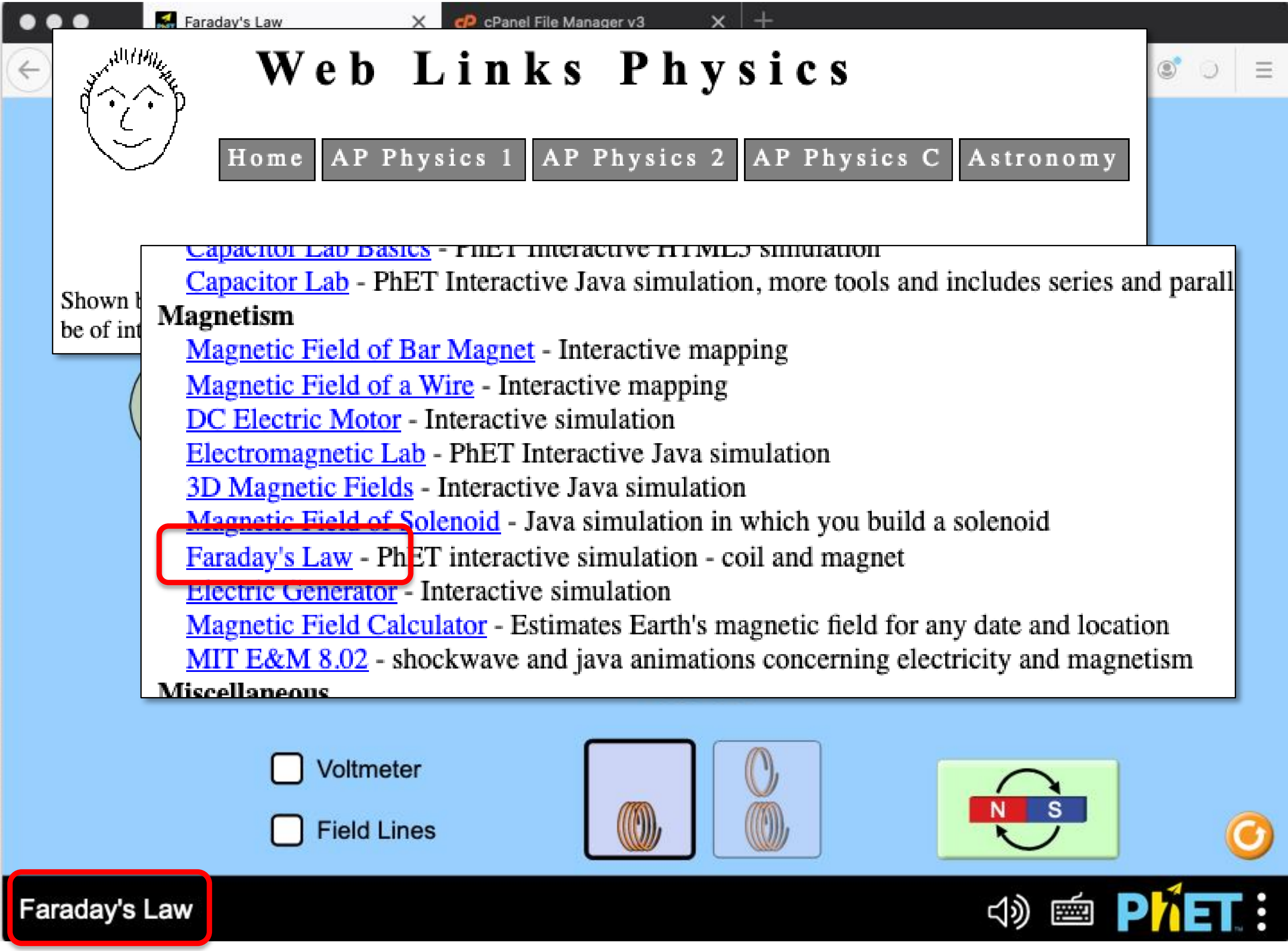
Magnetic Induction

Faraday’s Law, Lenz’s Law

	The student will be able to:	HW:
1	State and apply Faraday's Law and Lenz's Law and solve magnetic induction problems involving changing magnetic flux, and induced emf or eddy currents.	1 – 16
2	Solve problems involving basic principles of generators, including production of back emf.	17 – 21
3	State and recognize Maxwell's equations and associate each equation with its implications.	22 – 23
4	Define and calculate inductance and solve related problems including those that involve parallel or series inductors.	24 – 31
5	Analyze RL circuits in terms of the appropriate differential equation and resulting exponential functions for charge, current, voltage, etc.	32 – 38
6	Analyze LC and RLC circuits in terms of the appropriate differential equation and resulting exponential functions for charge, current, voltage, etc.	39 – 41

Induction

- Just as an electric field can induce an electrostatic charge, a magnetic field can induce a current.


Faraday's Law
cPanel File Manager v3
Web Links Physics
Home
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Capacitor Lab - PhET Interactive Java simulation, more tools and includes series and parall
Magnetism
Magnetic Field of Bar Magnet - Interactive mapping
Magnetic Field of a Wire - Interactive mapping
DC Electric Motor - Interactive simulation
Electromagnetic Lab - PhET Interactive Java simulation
3D Magnetic Fields - Interactive Java simulation
Magnetic Field of Solenoid - Java simulation in which you build a solenoid
Faraday's Law - PhET interactive simulation - coil and magnet
Electric Generator - Interactive simulation
Magnetic Field Calculator - Estimates Earth's magnetic field for any date and location
MIT E&M 8.02 - shockwave and java animations concerning electricity and magnetism
Miscellaneous
Voltmeter
Field Lines
N
S
Faraday's Law
PhET

Questions to Explore

- How does the motion of the magnet affect the electricity generated – what produces the greatest current and voltage?
- What determines the direction of current?
- Is there any position at which magnet produces electricity if it is not moving?
- Is there any position at which the magnet produces no electricity if it is moving?
- What is the effect of having more turns in the coil? Look closely at how circuit is wired.

Induction

- Just as an electric field can induce an electrostatic charge, a magnetic field can induce a current.
- However, it is observed that only a *changing* magnetic field can result in a current – presence of a *static* magnetic field will <u>not</u> induce a current.
- If current exists, it follows that there must be voltage, which in this case is called emf ("electromagnetic force").

Faraday's Law

$$\varepsilon = -\frac{d\Phi_M}{dt}$$

where: ε = induced emf

Φ_M = magnetic flux

t = time

Magnetic Flux

$$\phi_M = \int \vec{B} \cdot d\vec{A}$$

where: Φ_M = magnetic flux
B = magnetic field
A = area

SI unit: 1 weber = 1 tesla·1 meter^2
Wb = T·m^2

Variations of Faraday's Law

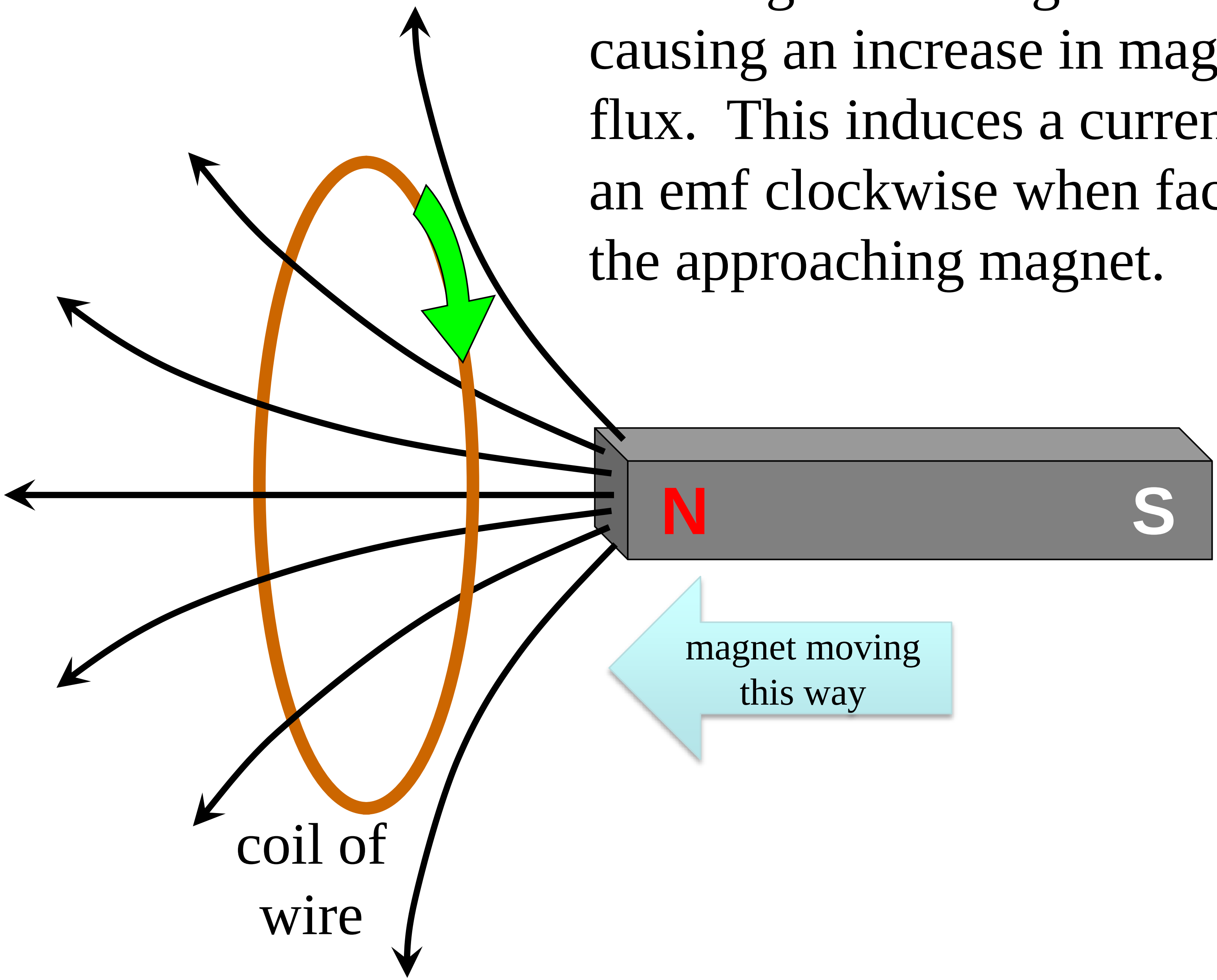
$$\varepsilon = -\frac{d\Phi_M}{dt}$$

$$\Phi_M = \int \vec{B} \cdot d\vec{A}$$

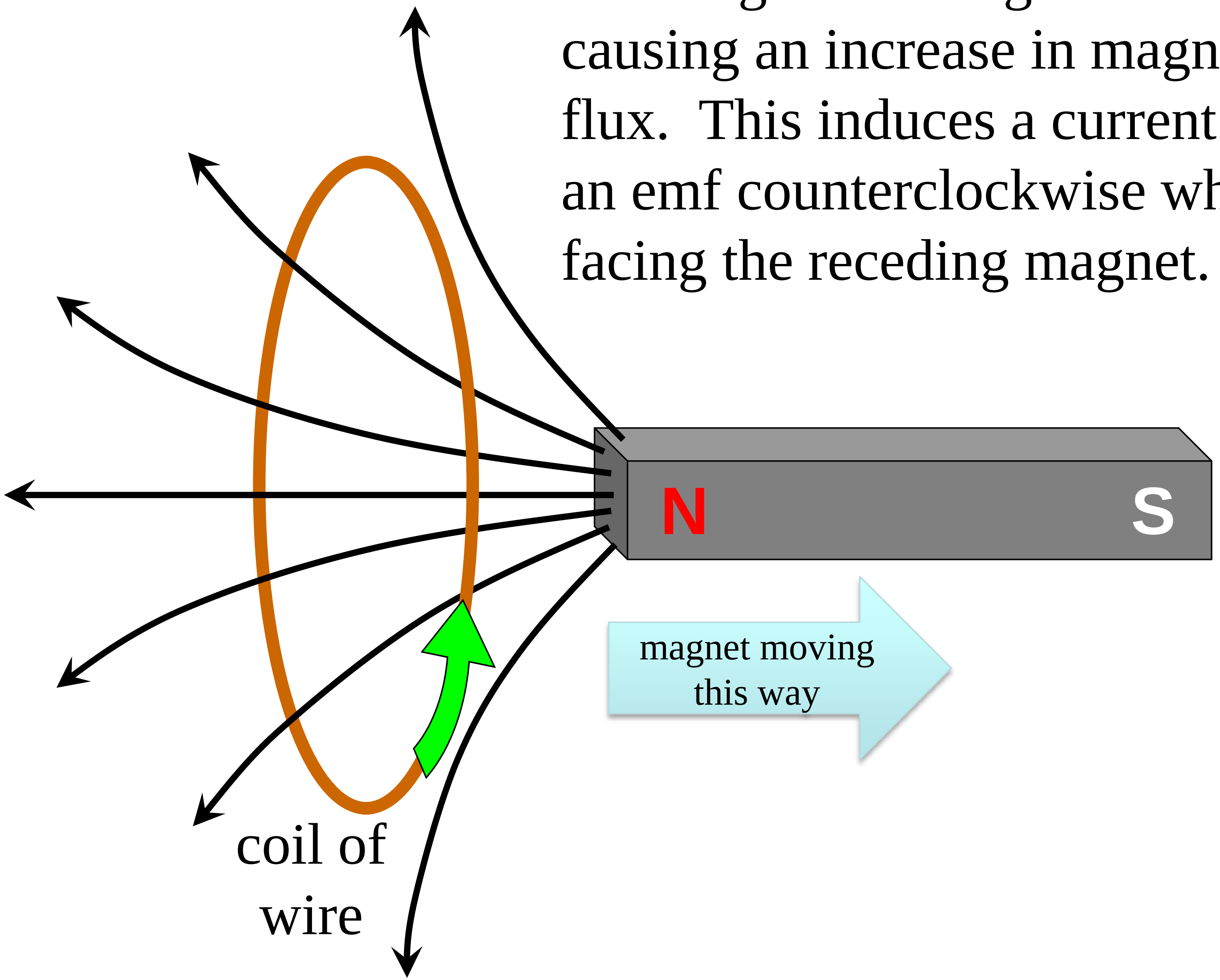
Variations of Faraday's Law

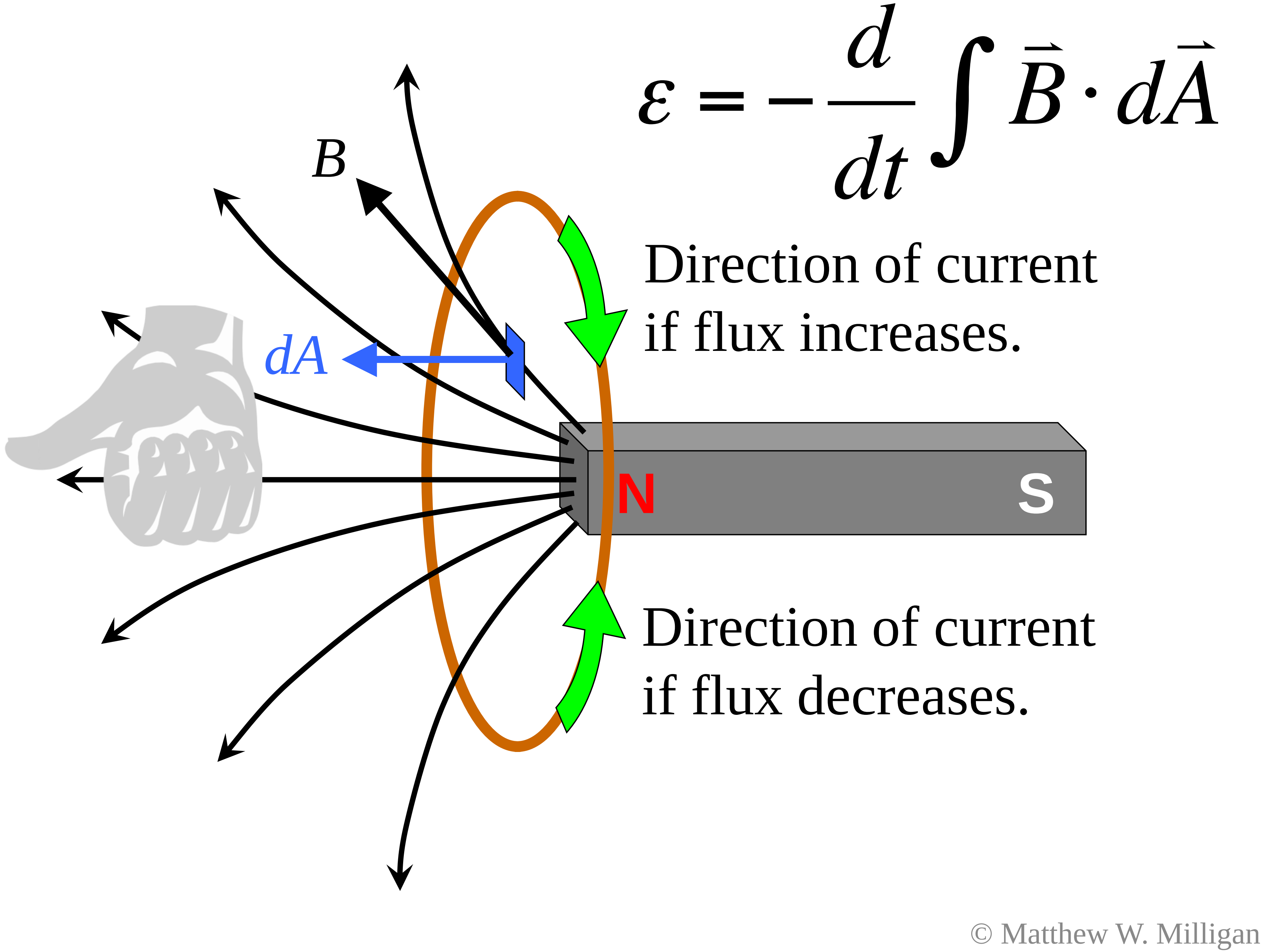
$$\varepsilon = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A}$$

The magnet moving to the left is causing an increase in magnetic flux. This induces a current and an emf clockwise when facing the approaching magnet.



The magnet moving to the right is causing an increase in magnetic flux. This induces a current and an emf counterclockwise when facing the receding magnet.




$$\varepsilon = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A}$$
B
dA
Direction of current
if flux increases.
N
S
Direction of current
if flux decreases.
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About the Induced EMF

- The negative sign in Faraday's Law indicates the sense of the induced emf.
- The direction in which this emf drives current is referred to as the "sense" of the emf.
- Unlike other voltage sources, an induced emf is not the potential difference between two points (like the terminals of a battery).
- Rather, the induced emf represents "work or energy per charge" "around and along a path".

Lenz’s Law

- When a changing magnetic flux induces a current, the induced current *itself* will create an *additional* magnetic field.
- The induced current will always produce a magnetic field that opposes the *change* in magnetic flux.
- If magnetic flux is increasing then the induced magnetic field will point opposite the original.
- This is an easier method for finding the sense of the emf than using the RHR and negative sign in Faraday’s Law.

Variations of Faraday's Law

$$\varepsilon = -\frac{d}{dt}\int \vec{B} \cdot d\vec{A}$$

$$V_B - V_A = -\int_A^B \vec{E} \cdot d\vec{\ell}$$

Variations of Faraday's Law

$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{d}{dt}\int \vec{B} \cdot d\vec{A}$$

The product of electric field and length of path is the same as that used to find a potential *difference* between two points. *However*, in this case it represents a *voltage "around"* a closed path. Is *this* electric field conservative?

NO!

The Induced Electric Field

$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{d}{dt}\int \vec{B} \cdot d\vec{A}$$

The electric field in *this* equation is an *induced* electric field and has different properties than a "regular" *electrostatic* field.

The induced electric field lines are continuous closed loops. This field can do work on charged particles that circulate along a loop.