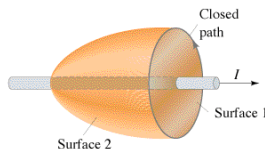


**PHY385-H1F Introductory Optics**  
Class 4 – Outline: Sec. 3.3, 3.4

- Finishing Constraints on the EM-wave imposed by Maxwell's Equations
- Poynting Vector
- Irradiance
- Photons
- Radiation Pressure and Momentum
- Synchrotron Radiation
- Electric Dipole Radiation
- Emission

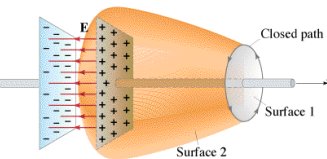
• Ampere's Original Law:

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}}$$


- Normally when we think of Ampere's law, we consider a closed path enclosing surface 1
- But we could have considered surface 2
- In this case, the current enclosed is the same as for surface 1
- The current flowing into any volume must equal that coming out, as long as the charge within that volume is constant.

**Maxwell's Paradox**

- Suppose we have a charged capacitor and it begins to discharge

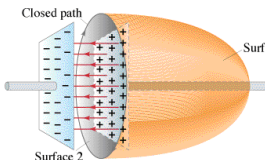


Surface 1 works, but surface 2 has *no current passing through*, yet there is a magnetic field around the closed path.

**Maxwell's Paradox**

Same problem here. Surface 1 works, but no current passes through Surface 2 – even though the closed path along which we must integrate the magnetic field is the same for both.

What is happening???

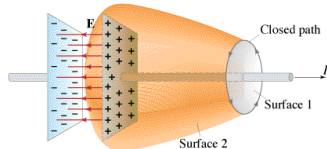


**Ampere's Law – Complete Version**

- While the capacitor is discharging, a current flows
- The electric field between the plates of the capacitor is *decreasing* as current flows
- Maxwell said the *changing electric field* is equivalent to a current
- He called it the **displacement current**
- Ampere's Law with Maxwell's correction is:

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}} + \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t}$$

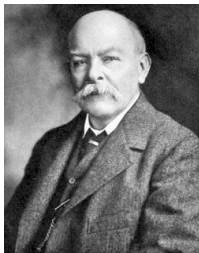
**In-Class Task from Last time.. I asked:**



- 1a. What is the current through surface 1? *I*
- 1b. What is the current through surface 2? *zero!*
- 1c. Should the loop integral of *B* around the closed path be the SAME or DIFFERENT for the two surfaces? *SAME*
2. How can Ampère's Law be applied to this situation? *You must include the displacement current (Maxwell's correction, related to d/dt of electric flux through the surface)*

## Poynting Vector

- John Poynting
- 1884 published a paper describing a vector which is “pointing” in the direction of energy flow of an electromagnetic wave!
- This was 20 years after Maxwell first described electromagnetic waves.



John Henry Poynting

## Poynting Vector

$$\vec{S} = \vec{E} \times \vec{H}$$

or

$$\vec{S} = \epsilon_0 c^2 (\vec{E} \times \vec{B})$$

Units: W/m<sup>2</sup>

In a propagating sinusoidal electromagnetic plane wave of a fixed frequency, the Poynting vector oscillates, always pointing in the direction of propagation. The time-averaged magnitude of the Poynting vector is:

$$\langle S \rangle = \frac{1}{2\mu_0 c} E_0^2 = \frac{\epsilon_0 c}{2} E_0^2$$

where  $E_0$  is the amplitude of the electric field oscillations.

## 5-minute In-Class Task

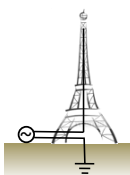
- Please take out a piece of paper that you don't mind handing to me at the end
- WRITE YOUR NAME at the top of the piece of paper
- Discussion with your friends or me during this task is *encouraged!*

Consider a big transmitting tower, which is aligned with the vertical  $+z$  axis. Choose coordinates so that  $+z$  is up,  $+x$  is East, and  $+y$  is North.

An AC generator is connected to the tower, sending a current up and down its length.

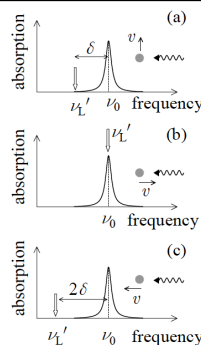
If you are in a car 1 km East of the tower:

1. Along which direction ( $x$ ,  $y$  or  $z$ ) will the electric field oscillate near your car?
2. Along which direction ( $x$ ,  $y$  or  $z$ ) will the magnetic field oscillate near your car?



Important note for our Monday tour of Professor Thywissen's Lab:

## Doppler cooling mechanism



- absorption only for case (b)
- laser must be tuned below the transition
- frequency must be tuned as atoms cool

