Exam 2 scores are posted. Class average was 79. Answers are on gradebook. Solution will be posted on class web site.

Final exam is Monday, December 17 from 12-3 here (PLH) You can use 3 8.5”x11” sides of self-prepared notes.
STEP BY STEP FOR SINGLE LOOP AC CIRCUITS

1. Choose the current direction and label the capacitor charges
2. Apply loop rule to write the complex number equation
3. Solve the equation
4. Talk about power and energy

You can go back and forth between complex numbers and sinusoidal varying functions

\[ F_m e^{i\phi} \]
\[ F(t) = \text{Re}(F_m e^{i\phi} e^{i\omega t}) = F_m \cos(\omega t + \phi) \]
Simple AC circuits: $E(t) = E_m \cos(\omega_d t)$

Current and the potential drop are in phase

$E - i_R R = 0$

$i_R = E / R$

Current and the potential drop are in phase

Average power delivered by the emf source is

$\frac{E i_R}{2} = \frac{E_{\text{rms}} i_{R,\text{rms}}}{2}$
What if the current is NOT in phase with the emf source?

\[ I(t) = I_m \cos(\omega t + \phi) \]

Power delivered by the emf source is

\[ E \cos(\omega t) I_m \cos(\omega t + \phi) \]

averaged over one cycle

Use angle addition formula

\[ \cos(\omega t + \phi) = \cos(\omega t) \cos\phi + \sin(\omega t) \sin\phi \]

\[ EI \cos\phi/2 = E_{\text{rms}} I_{\text{rms}} \cos\phi \]

Cos \( \phi \) is called the “power factor”
Current lags the potential drop by $\pi/2$

Energy delivered by the emf source

Power factor is zero
Loop rule: \[ \frac{Q(t)}{C} + Ri(t) + L \frac{di(t)}{dt} = E_m \cos(\omega t) \]
\[ \frac{Q(t)}{C} + R \frac{dQ(t)}{dt} + L \frac{d^2Q(t)}{dt^2} = E_m \cos(\omega t) \]

\[ \frac{Q_t}{C} + Ri_0Q_t - L\omega^2 Q_t = E_m \]
Solve this linear equation for complex number \( Q_t \)
\[ Q_t = \frac{E_m}{(1/C - \omega^2L + i\omega R)} \]

\[ Q(t) = \text{Re} \left( Q_t e^{i\omega t} \right) \]
\[ I(t) = \text{Re}(i\omega Q_t e^{i\omega t}) \]
Get the amplitude and the phase of \( I \)

LOOK AT THE POWER DELIVERED BY THE EMF SOURCE
\[ E_{\text{rms}} \ I_{\text{rms}} \ \cos \phi \] (power factor)
TRANSFORMER – great illustration
Φ_B is the same in both coils

\[ I_s = \left( \frac{N_2}{N_1} \right) \frac{E^2}{R} \]

Step up
Step down

\[ V_s = V_p \frac{N_s}{N_p} \]
Chapter 32

Maxwell’s Equations

the set of four equations that relate
the vector fields $E(r,t)$ and $B(r,t)$ to
charge distribution $\rho(r,t)$ and current density $j(r,t)$
Electromagnetism

\[ \oint \vec{E} \cdot d\vec{A} = q_{\text{enc}}/\varepsilon_0 \quad \oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \]

\[ \oint \vec{B} \cdot d\vec{A} = 0 \quad \oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{\text{enc}} \]

Maxwell’s equations: fields, charge, current

\[ \mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}). \]
Electromagnetism

\[ \int \vec{E} \cdot d\vec{A} = q_{\text{enc}}/\varepsilon_0 \]

\[ \int \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \]

\[ \int \vec{B} \cdot d\vec{s} = \mu_0 i_{\text{enc}} \]

Maxwell’s equations: fields, charge, current

\[ \mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \]
A changing magnetic field produces an electric field.

This is in addition to the electric field produced by charges.

Does a changing ELECTRIC field produce a MAGNETIC field? YES!

This is in addition to magnetic fields produced by currents: “displacement current” density $\varepsilon_0 \frac{d\Phi_E}{dt}$ : Ampere’s law

$$\oint \vec{E} \cdot d\vec{s} = - \frac{d\Phi_B}{dt} \quad \text{(Faraday’s law).}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$
Before charging, there is no magnetic field.

During charging, magnetic field is created by both the real and fictional currents.

During charging, the right-hand rule works for both the real and fictional currents.

After charging, there is no magnetic field.
Electromagnetism

\[ \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0} \]
\[ \oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \]

\[ \oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{\text{enc}} \]

Maxwell’s equations: fields, charge, current

\[ \mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}). \]
Gauss’ Law

\[ \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0} \]

Graphical approach to computing flux integral:
Flux integral is proportional to # of field lines out - # of field lines in

Electric field lines begin on positive charges, end on negative charges

What about magnetic field lines?
form closed loops – no beginning or ending

\[ \oint \vec{B} \cdot d\vec{A} = 0 \]
First Results from a Superconductive Detector for Moving Magnetic Monopoles

Blas Cabrera

Physics Department, Stanford University, Stanford, California 94305
(Received 5 April 1982)

A velocity- and mass-independent search for moving magnetic monopoles is being performed by continuously monitoring the current in a 20-cm²-area superconducting loop. A single candidate event, consistent with one Dirac unit of magnetic charge, has been detected during five runs totaling 151 days. These data set an upper limit of 6.1 × 10⁻¹⁰ cm⁻² sec⁻¹ sr⁻¹ for magnetically charged particles moving through the earth's surface.

PACS numbers: 14.80.Hv
Electromagnetism

\[ \oint \vec{E} \cdot d\vec{A} = q_{\text{enc}}/\varepsilon_0 \quad \oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \]

\[ \oint \vec{B} \cdot d\vec{A} = 0 \quad \oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{\text{enc}} \]

Maxwell’s equations: fields, charge, current

\[ \mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}). \]
Electromagnetism

\[ \nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \]

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]

\[ \nabla \cdot \mathbf{B} = 0 \]

\[ \nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t} \cdot \]

Maxwell’s equations: fields, charge, current

\[ \mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \]
Next time: “Let there be light”
electromagnetic waves