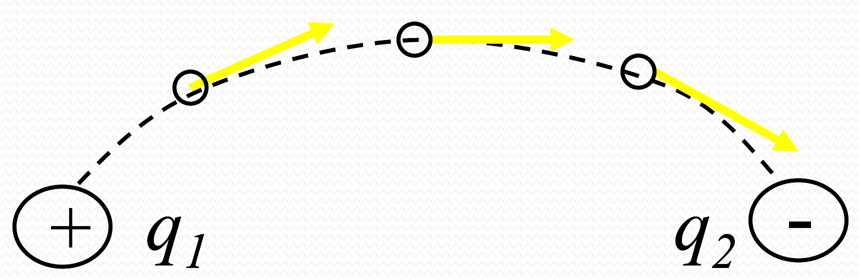
Maxwell's Theory

Electromagnetic theory developed by James Maxwell (1831 – 1879) is based on four concepts:

1. Electric fields E begin on positive charges and end on negative charges and Coulomb's law can be used to find the field E and the force on a given charge.

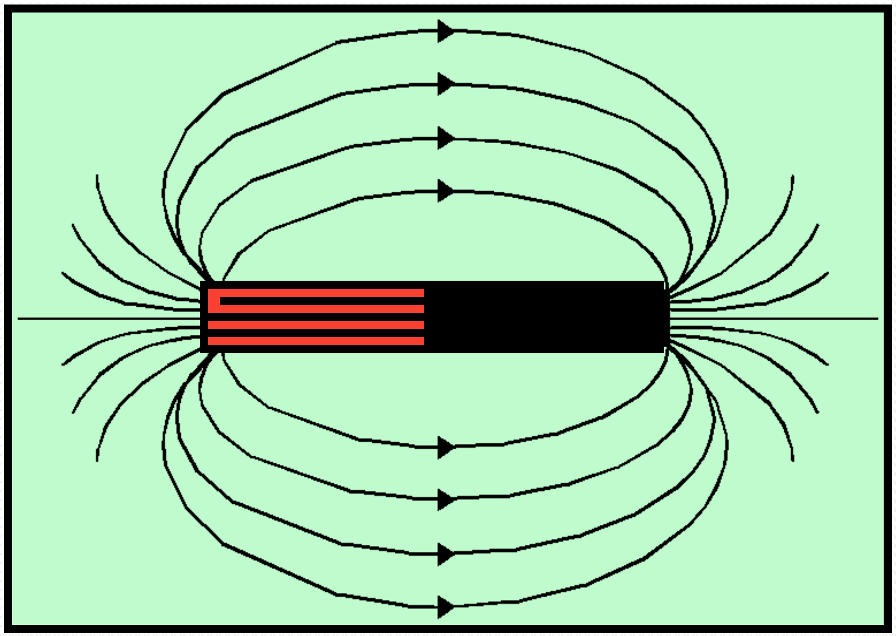


$$E = \frac{q}{4\pi\varepsilon_0 r^2}$$

$$F = qE$$

Maxwell's Theory

2. Magnetic field lines Φ do not begin or end, but rather consist of entirely closed loops.



$$B = \frac{\Phi}{A \sin\theta}$$

$$B = \frac{q}{qv \sin\theta}$$

Maxwell's Theory

3. A changing magnetic field ΔB induces an emf and therefore an electric field E (Faraday's Law).

Faraday's Law:
$E = -N \dfrac{\Delta \Phi}{\Delta t}$

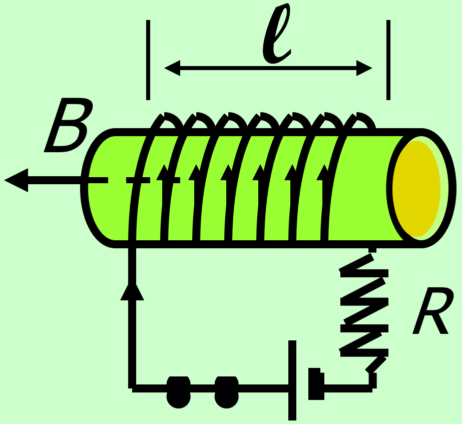
A change in flux $\Delta\Phi$ can occur by a change in area or by a change in the B-field:

$\Delta\Phi = B\,\Delta A$ $\quad$ $\Delta\Phi = A\,\Delta B$

Maxwell's Theory

4. Moving charges (or an electric current) induce a magnetic field B.

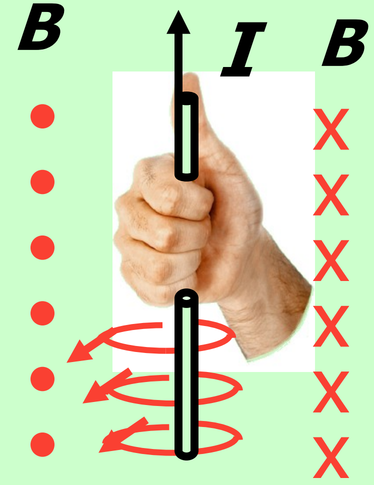
Solenoid



Inductance *L*

Current *I* induces *B* field

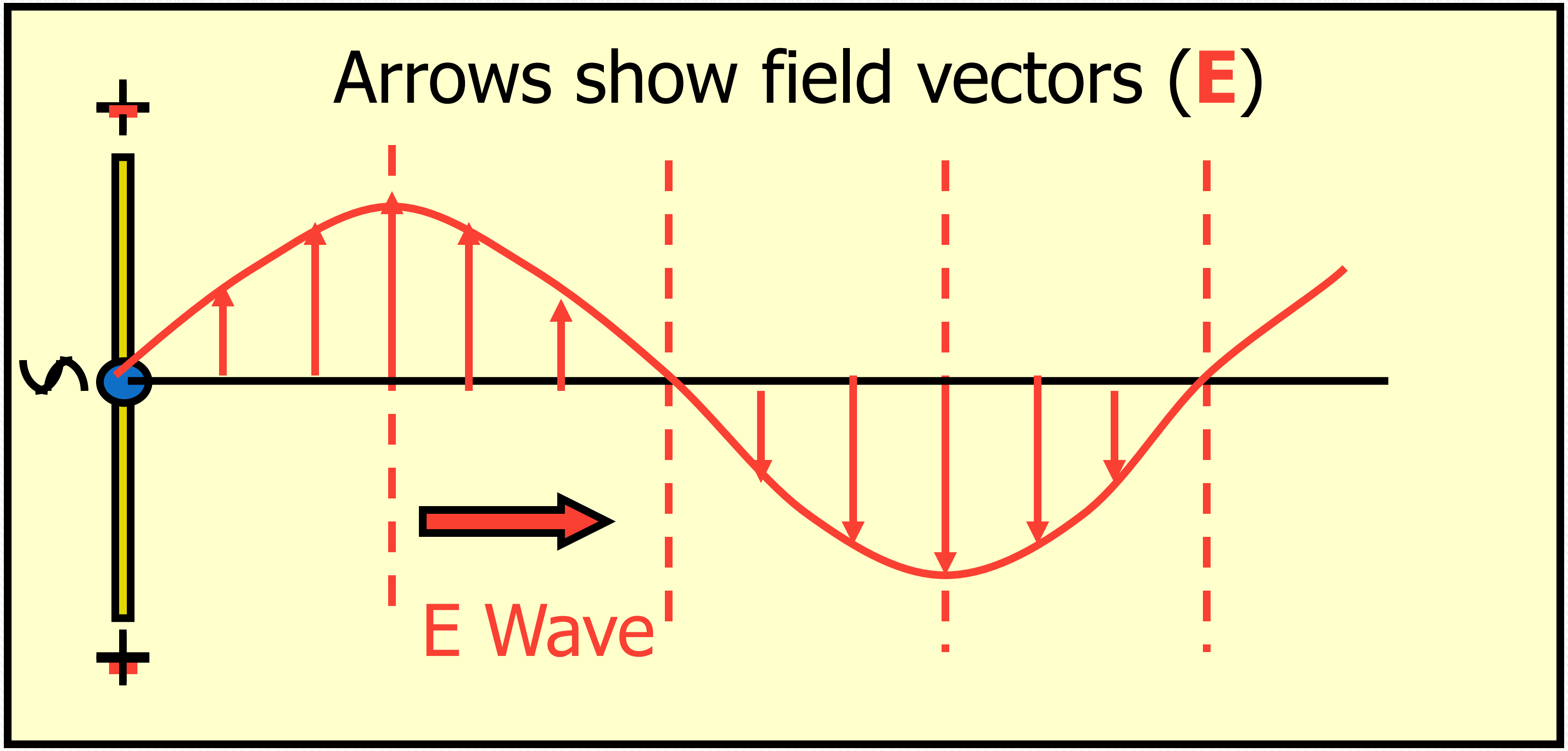
$$B = \frac{\mu_0 N I}{\ell}$$



Lenz's law

Production of an Electric Wave

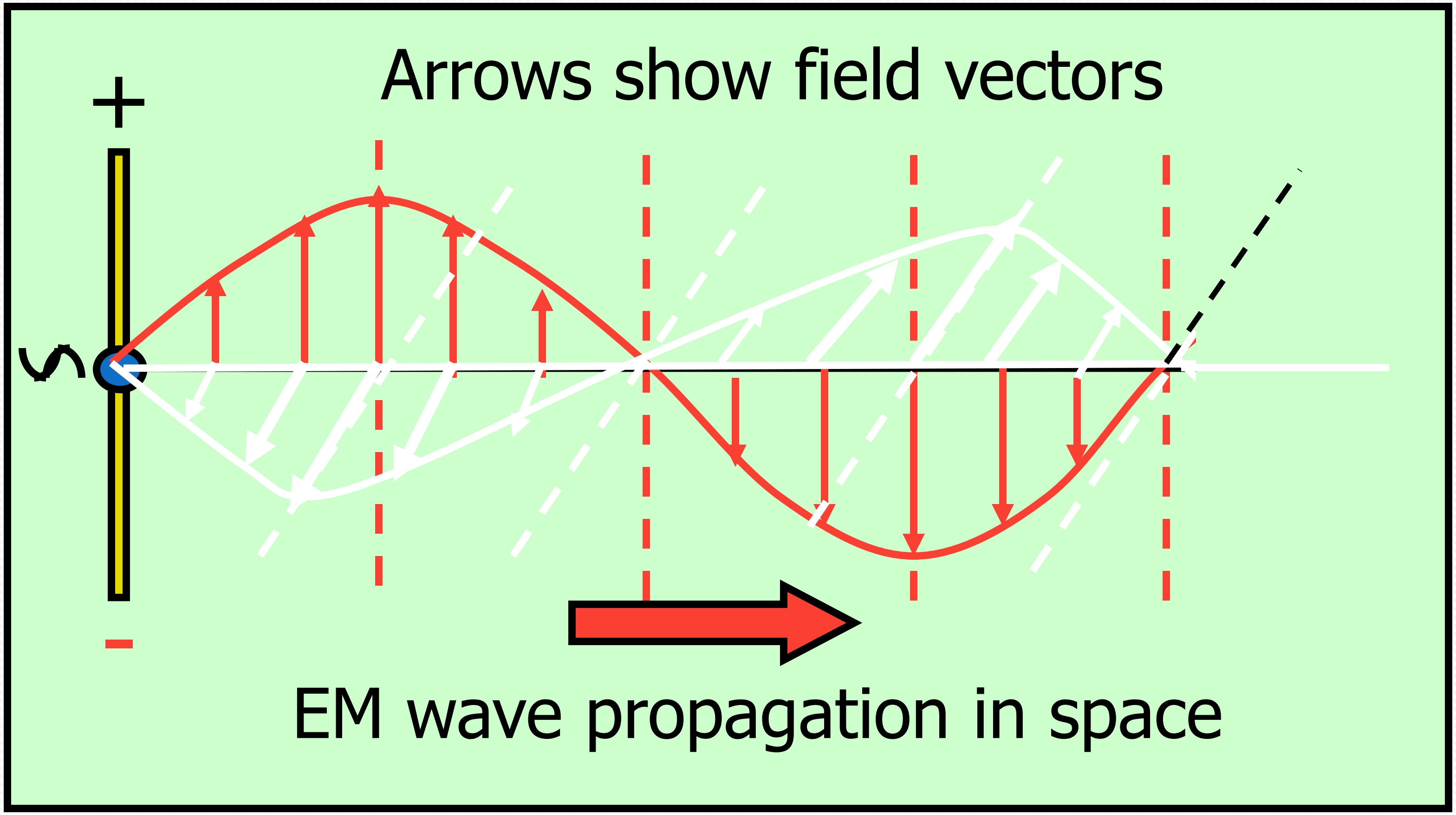
Consider two metal rods connected to an ac source with sinusoidal current and voltage.



Vertical transverse sinusoidal E-waves.

An Electromagnetic Wave

An electromagnetic wave consists of combination of a transverse electric field and a transverse magnetic field perpendicular to each other.



Energy Density for an E-field

Energy density *u* is the energy per unit volume (J/m^3) carried by an EM wave. Consider *u* for the electric field *E* of a capacitor as given below:

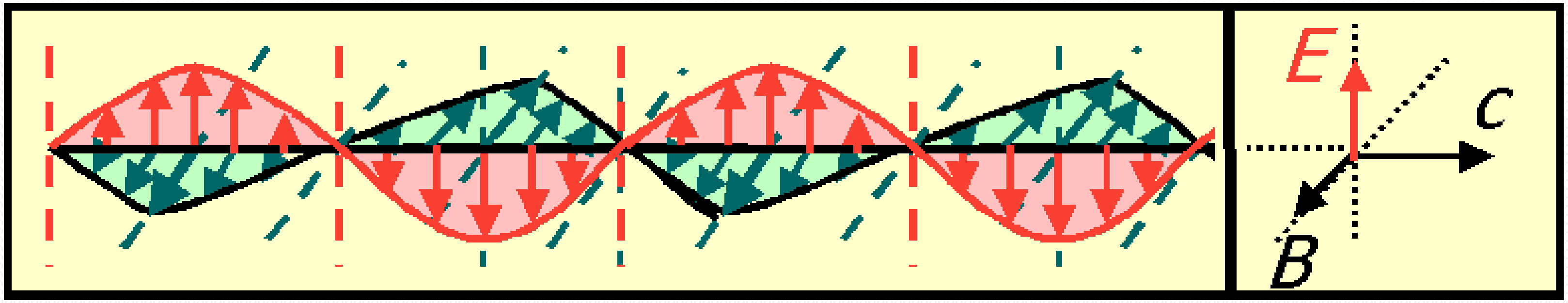
Energy density u for an E-field:

$$u = \frac{U}{Vol.} = \frac{U}{Ad}$$

Energy density u:

$$u = \tfrac{1}{2}\varepsilon_0 E^2$$

Energy Density for EM Wave



The energy of an EM wave is shared equally by the electric and magnetic fields, so that the total energy density of the wave is given by:

Total energy density: $u = \frac{1}{2}\varepsilon_0 E^2 + \frac{B^2}{2\mu_0}$

Or, since energy is shared equally: $u = \varepsilon_0 E^2 = \frac{B^2}{\mu_0}$

Summary

EM-waves travel at the speed of light, which is:

$c = 3.00 \times 10^8$ m/s

$$c = \frac{E}{B}$$

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

Total Energy Density: $u = \frac{1}{2}\varepsilon_0 E^2 + \frac{B^2}{2\mu_0}$

$$E_{rms} = \frac{E_m}{\sqrt{2}} \quad \text{and} \quad B_{rms} = \frac{B_m}{\sqrt{2}}$$

Summary

The average energy density:

$$u_{avg} = \tfrac{1}{2}\varepsilon_0 E_m^2 \quad \text{or} \quad u_{avg} = \varepsilon_0 E_{rms}^2$$

$$I_{avg} = \tfrac{1}{2} c\varepsilon_0 E_m^2 = c\varepsilon_0 E_{rms}^2$$

Intensity and Distance	Totally Absorbing	Totally Reflecting
$I = \frac{P}{A} = \frac{P}{4\pi r^2}$	$\frac{F}{A} = \frac{I}{c}$	$\frac{F}{A} = \frac{2I}{c}$