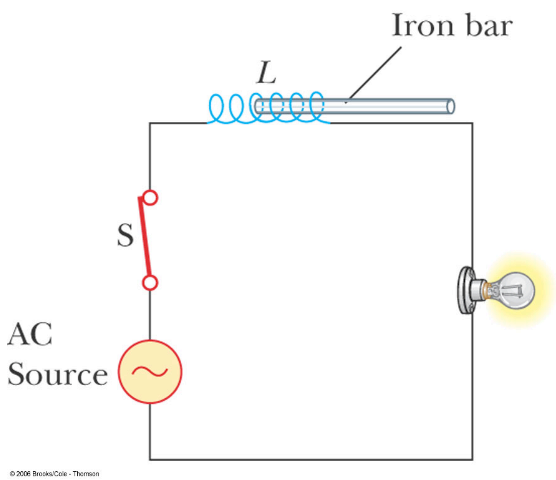
Quick Quiz 20.5

In this RL circuit, driven by an AC source of EMF, the inductor is an air-core solenoid.



The switch is closed and after some time, the light bulb glows steadily.

An iron rod is inserted into the solenoid, thereby increasing the strength of the B-field inside the solenoid. As the rod is being inserted, what happens to the brightness of the light bulb?

Answer: L is increasing. So $|\Delta V_L| = L(\Delta I/\Delta t)$ is increasing.

$\varepsilon = \Delta V_R + \Delta V_L$

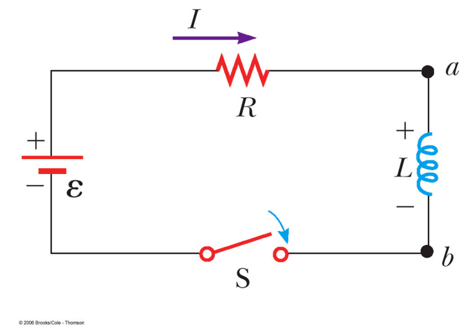
ΔV_R is decreasing, the power dissipated in the lightbulb decreases, and its brightness **decreases.**

Energy stored in an inductor

EMF induced by the inductor prevents the battery from establishing the maximum current immediately. Battery must do extra work to produce current.

Extra work: becomes potential energy stored in the B-field of the inductor

$$PE = 1/2\ L\ I^2$$



An RL circuit switch is closed at t=0, and the current begins to increase. R = 0.5Ω. L = 3×10^{-3}H. ε = 9V.

How much potential energy is stored in the inductor at t=0, and t=∞?

At t=0: I=0.   PE = 1/2 L I^2 = 0

At t=∞: I = ε/R: PE = 1/2 L I^2

= 1/2 L $(\varepsilon/R)^2$ = 0.49J

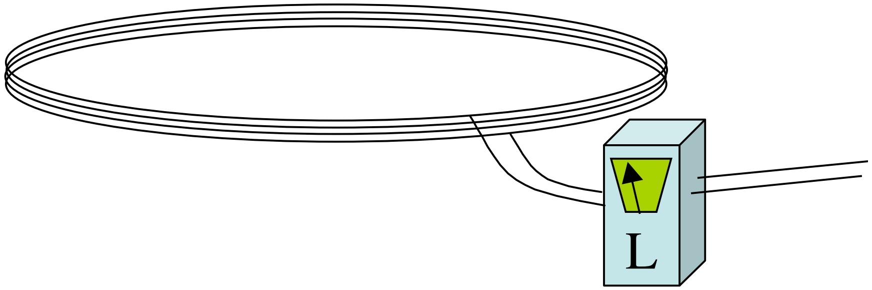
Application: traffic signals

Several coils of wire create a solenoid

Air-core $L = (\mu_0 (N^2/\ell))A$

"car-core": L increases by μ/μ_0

Device which measures inductance registers the change, triggers green signal.



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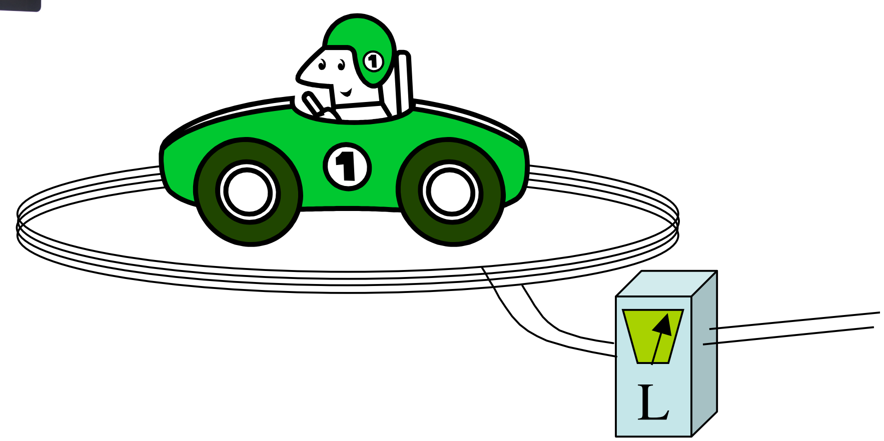

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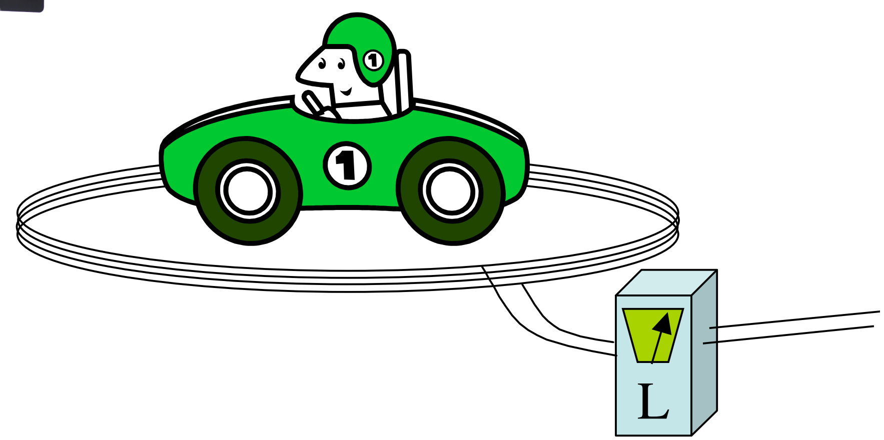


Device which measures inductance registers the change, triggers green signal.

Ch 21

Alternating-Current circuits

Voltage transformers

Maxwell's Predictions about EM radiation

Properties of EM radiation (light); the EM spectrum

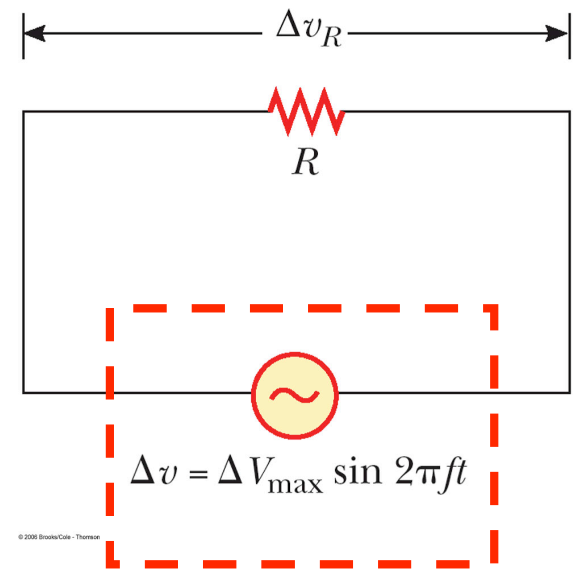
AC circuits: time-dependent voltage

AC generator drives voltage:

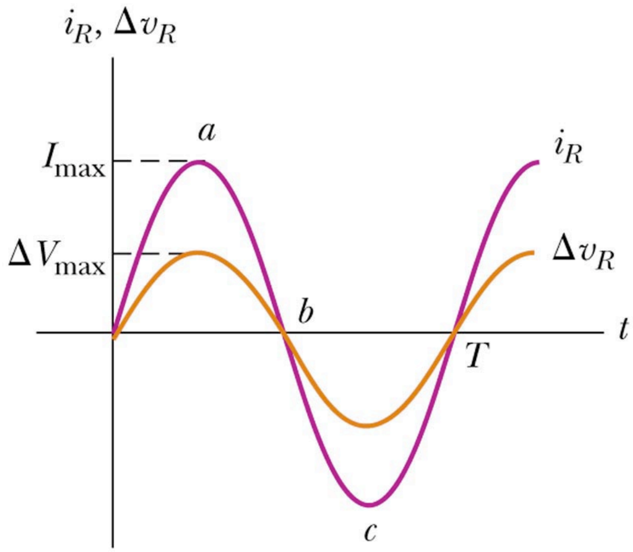
$$\Delta V = \Delta V_{max} \sin 2\pi f t$$

$$= \Delta V_{max} \sin \omega t$$

f = freq in Hz (cyc s^{-1}, or s^{-1})



AC circuit with a Resistor:



Plot of I(t) and ΔV_R(t)

They reach their max/min points simultaneously.

"Vary in phase"

What's the AVERAGE current over one cycle? Zero

What's the AVERAGE voltage over one cycle? Zero

But the direction of current has no effect on the behavior of the resistor: the same amount of power gets dissipated either way. You get the same frequency of collisions between the electrons and the molecular lattice

Recall $P = I^2R$: I =instantaneous current. P is the same whether I is + or –.

RMS current:

$$I_{rms} = \frac{I_{\max}}{\sqrt{2}} = 0.707\ I_{\max}$$

Average power dissipated through the resistor (over 1 or more cycles)

$$\wp_{av} = I_{rms}^2 R$$

RMS Voltage:

$$\Delta V_{rms} = \frac{\Delta V_{\max}}{\sqrt{2}} = 0.707\ \Delta V_{\max}$$

AC voltage of 120 V means that V_{max} = 170 V

Ohm's Law for an AC circuit with a resistor:

$\Delta V_{R,rms} = I_{rms}R$ and $\Delta V_{R,max} = I_{max}R$

Example:

Given: a 60-W lightbulb connected to a 120-volt (RMS) AC circuit. Calculate I_{rms}, R, I_{max} and ΔV_{max}

60 W is the average power dissipated. $P = I_{rms}^2 R = \Delta V_{R,rms} I_{rms}$

$I_{rms} = 0.5$ A

$R = P / I_{rms}^2 = 240\ \Omega$

$I_{max} = \sqrt{2}\, I_{rms} = 0.707$ A

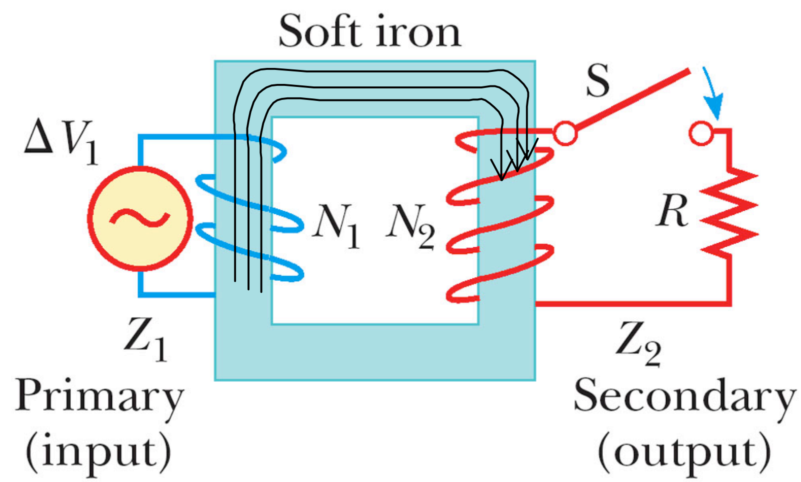
$\Delta V_{max} = \sqrt{2}\, \Delta V_{R,rms} = 170$ V

Note: $\Delta V_{max} = I_{max} R$

$170\text{V} = 0.707\text{A} \times 240\Omega$

Transformers

Device for transforming an AC voltage to a higher or lower AC voltage



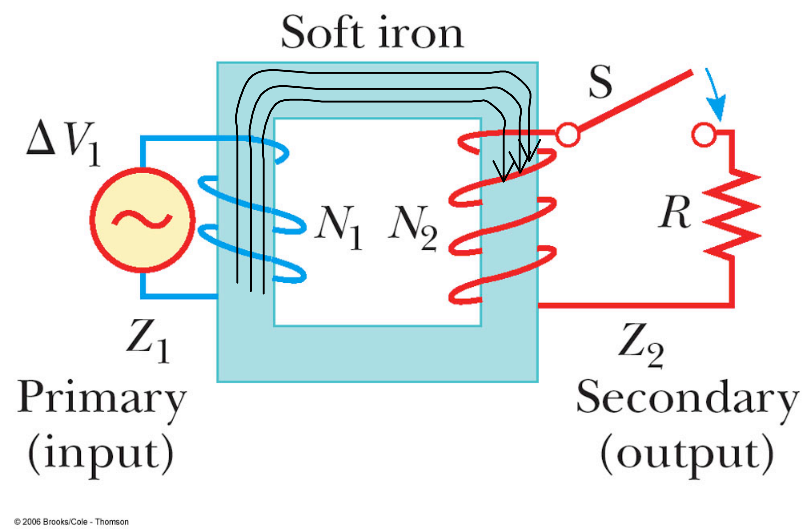
”Soft magnetic" iron core: increases the magnetic flux, and provides a medium such that nearly all Φ_B passing through coil 1 ends up in coil 2, too.

Transformers

voltage across primary:
$\Delta V_1 = -N_1 \Delta\Phi_B/\Delta t$

Induced voltage across secondary: $\Delta V_2 = -N_2 \Delta\Phi_B/\Delta t$

$$\frac{\Delta V_2}{\Delta V_1} = \frac{N_2}{N_1}$$



When $N_2 > N_1$ $\Delta V_2 > \Delta V_1$ -- it's a step-up transformer
When $N_2 < N_1$ $\Delta V_2 < \Delta V_1$ -- it's a step-down transformer

Power input = power output

$I_1 \Delta V_1 = I_2 \Delta V_2$

So in a step-up transformer, ΔV_2 may be very high but I_2 will be low

Demonstrates how transformers are useful in minimizing power loss

"IDEAL" transformer = 100% power transfer efficiency

Realistically, power transfer efficiencies may be 90-99%

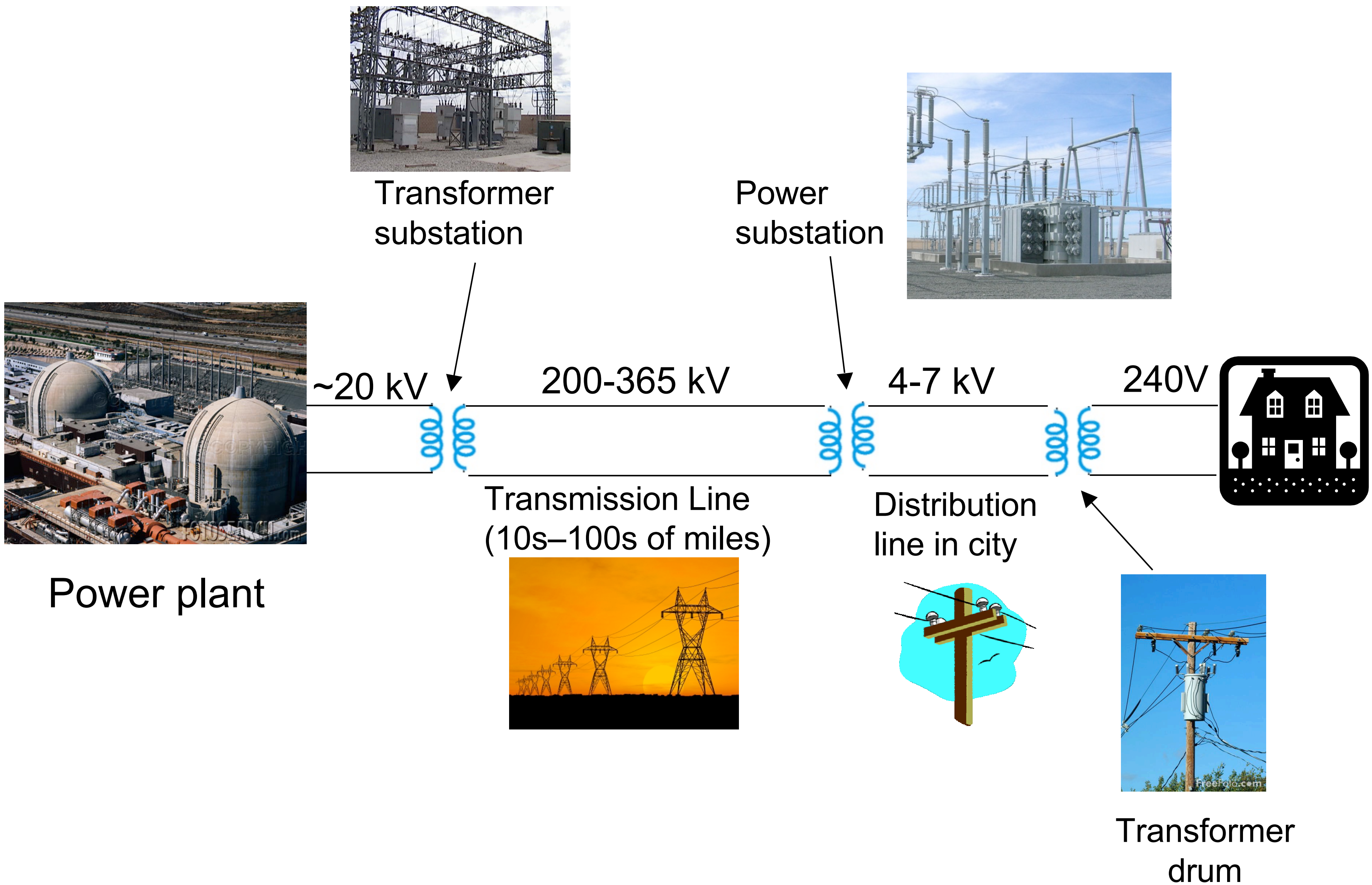
Electric Power Distribution

Recall why it’s useful to transmit power at high voltage and low I (minimizes resistive power losses during transmission).

But lower voltage is safer to handle.

So we use transformers to step-up/step-down voltage as needed

Electric Power Distribution



Ch. 21.8-21.13: Maxwell's Equations & Electromagnetic Waves

21.8: Maxwell’s Equations

Maxwell’s Equations….

… extend fundamental laws describing E and B to their most general form

… provide unification of E & M forces, previously thought to be unrelated

… predict the existence and properties of electromagnetic radiation (light)

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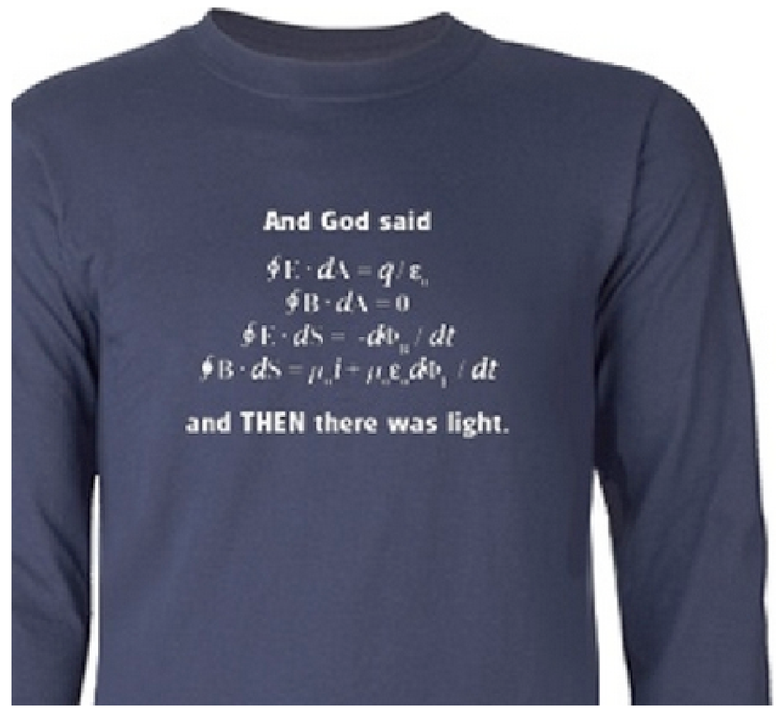

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Assembling the Four Laws of E+M

Law	Equation	WHAT IT SAYS
Gauss for E	$\Phi_E = Q_{encl} / \varepsilon_0$ for closed surface	How charges produce electric field; field lines begin and end on charges
Gauss for B	$\Phi_B = 0$ for closed surface	No magnetic charge; magnetic field lines do not begin or end
Faraday	$\varepsilon_{ind} = -N\frac{\Delta\Phi_B}{\Delta t}$	Changing magnetic flux produces electric field
Ampere	$\Sigma B_{\parallel} \Delta\ell = \mu_o I$	Electric current produces magnetic field

Maxwell's Correction to Ampere's Law

Maxwell hypothesized that a changing electric field ($d\Phi_E/dt$) could produce a magnetic field

TABLE 34-2 *Maxwell's Equations*

LAW	MATHEMATICAL STATEMENT	WHAT IT SAYS	EQUATION NUMBER
Gauss for **E**	$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{q}{\varepsilon_0}$	How charges produce electric field; field lines begin and end on charges	(34-2)
Gauss for **B**	$\oint \mathbf{B} \cdot d\mathbf{A} = 0$	No magnetic charge; magnetic field lines do not begin or end	(34-3)
Faraday	$\oint \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d\phi_B}{dt}$	Changing magnetic flux produces electric field	(34-4)
Ampère	$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$	Electric current and changing electric flux produce magnetic field	(34-5)

Maxwell's Eqns in Free Space (Vacuum)

Gauss for E

$\Phi_E = 0$ for closed surface: no charge to enclose

Gauss for B

$\Phi_B = 0$ for closed surface: no magnetic monopoles

Faraday

$$\varepsilon_{ind} = -N\frac{\Delta\Phi_B}{\Delta t}$$ Changing B-field can produce E

Ampere

$$\Sigma B_{||}\,\Delta\ell = \mu_o I + \varepsilon_0\, d\phi_E/dt$$

Changing E-field can produce B under certain conditions

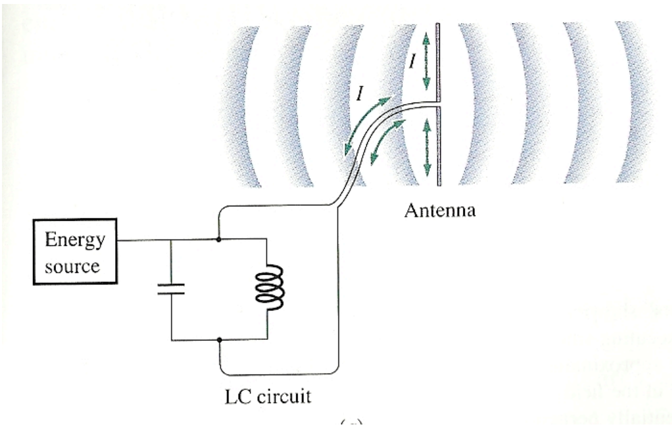
Maxwell’s Eqns in Free Space (Vacuum)

Changing B can produce E

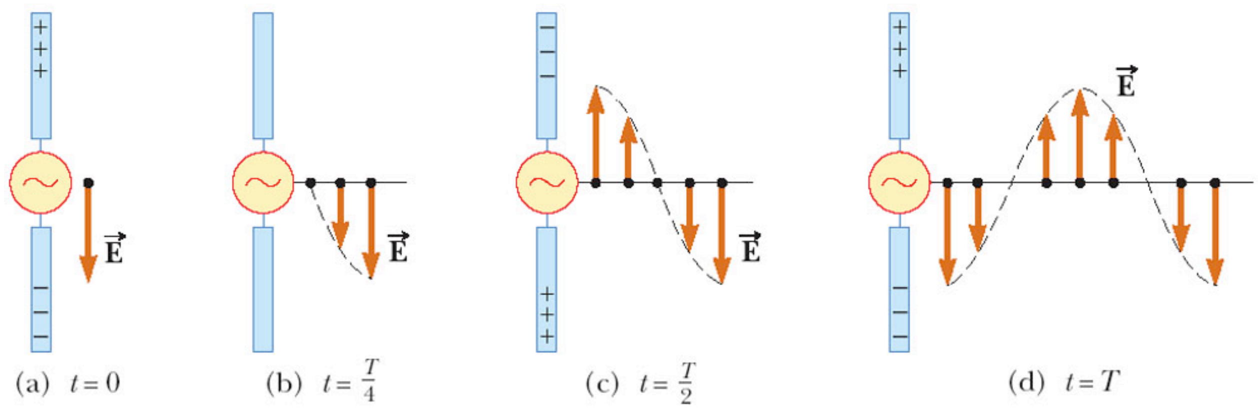
Changing E can produce B

EM WAVES: each type of field continually propagates the other

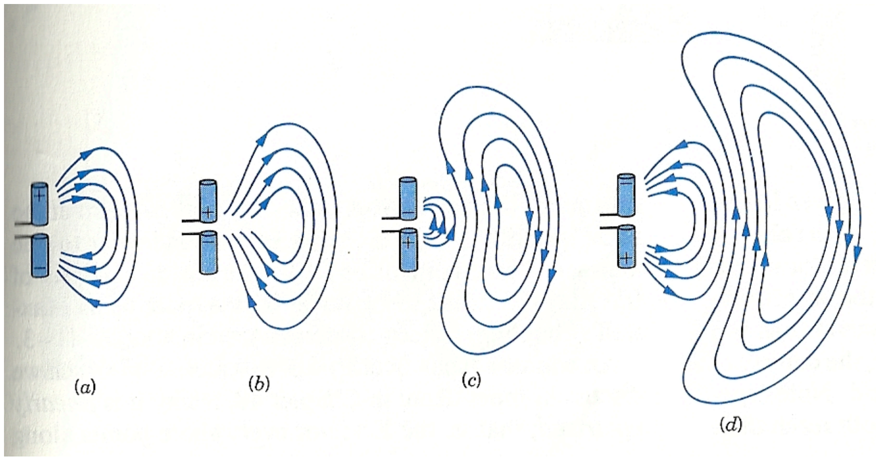
Radio transmitter



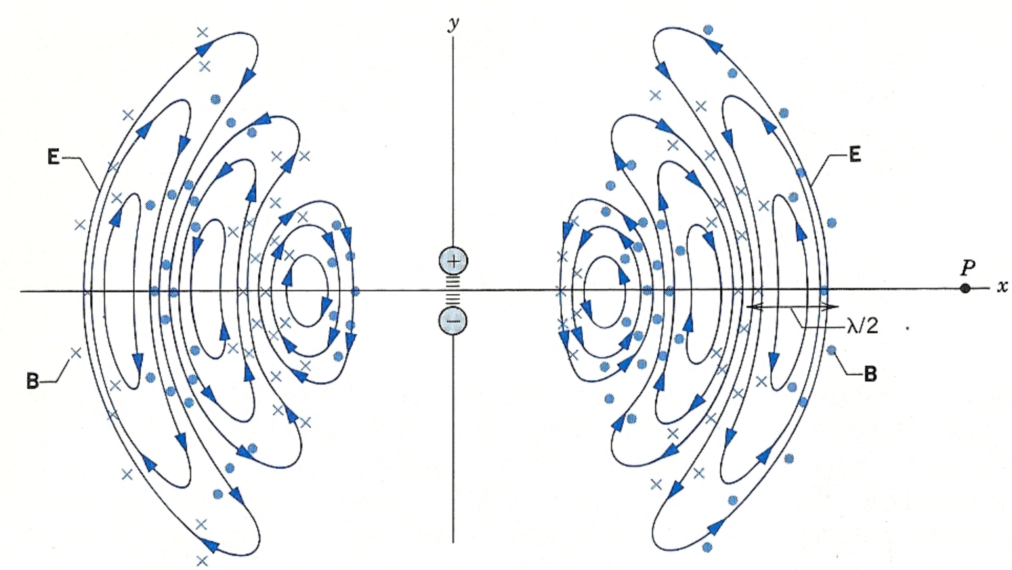
ACCELERATING CHARGES generate EM waves



Note that E-field oscillates in phase with charge distribution



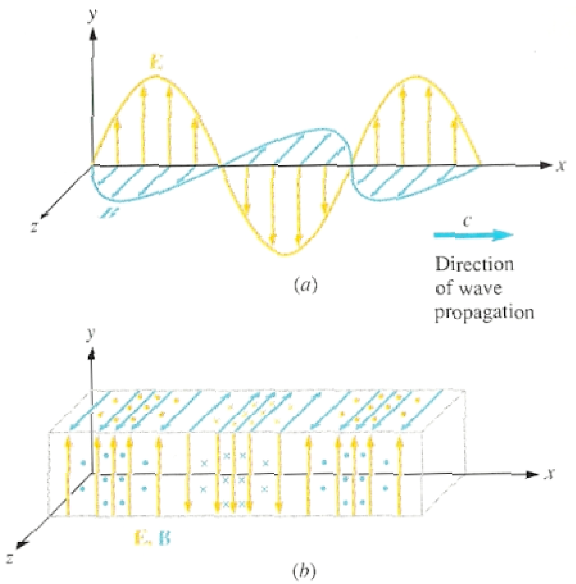
(E-field lines only)



(E- & B-field lines)

EM Plane Waves

Far from dipole, along x-axis….



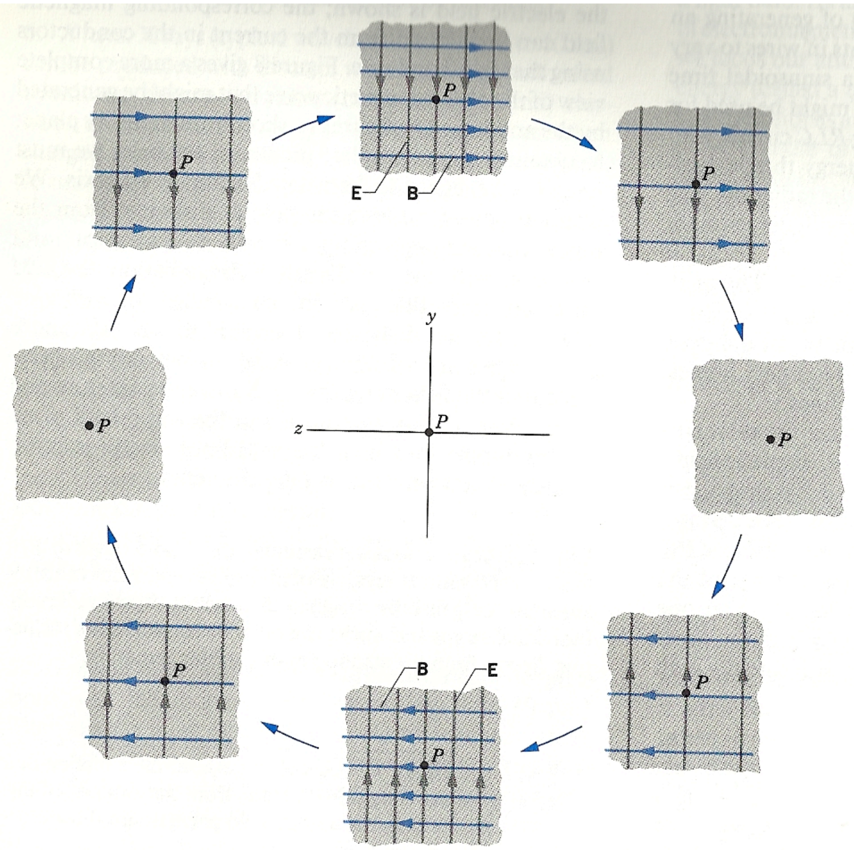


Figure 9 Eight
the plane electror
from the oscillati
served at point P.
travel of the wave
is out of the plane
E are vertical, and
zontal.

Note: $\vec{E}$ & $\vec{B}$ oscillate in phase

$\vec{E}$ & $\vec{B}$ are perpendicular to each other and to direction of propagation: $\vec{E} \times \vec{B} = \vec{v}$

Antennas (pre-digital TV)

Dipole antenna detects the E field (VHF)

Loop antenna detects the B field (UHF)

What are the directions of the E- & B-fields here?

What is the direction to the TV station?

Antennas (pre-digital TV)

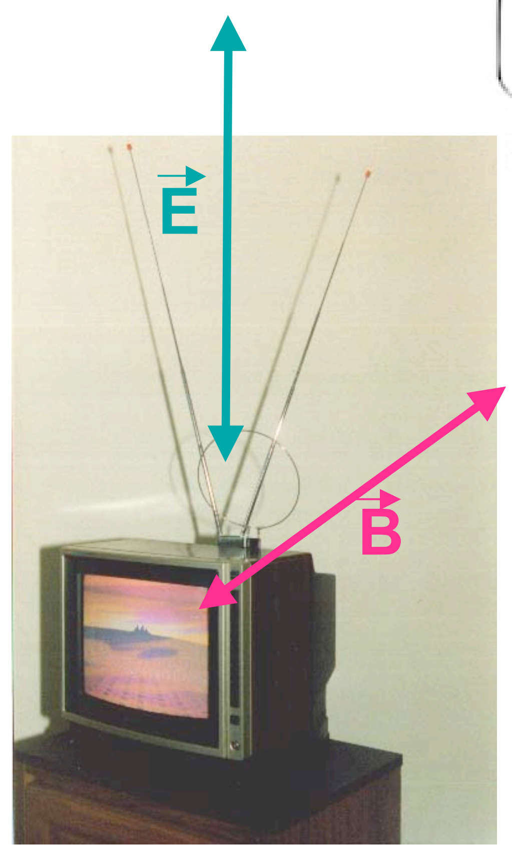
Dipole antenna detects the E field (VHF)

Loop antenna detects the B field (UHF)

What are the directions of the E- & B-fields here?

What is the direction to the TV station?

Direction of propagation is perpendicular to both E and B: So the TV station must be to the LEFT or RIGHT



Properties of EM Waves

1. E- and B-fields radiate as waves from an accelerating charge
2: Waves propagate at speed of light
3. Waves propagate in a vacuum
4. EM radiation carries energy and momentum

Faraday helped to unify electricity and magnetism. Now Maxwell had unified light, electricity and magnetism!

Maxwell's Equations Predict Speed of EM Waves

$$\text{Wave speed } c = \omega/k = \frac{1}{\sqrt{\epsilon_0\mu_0}}$$

$$= \frac{1}{\sqrt{(8.85\times10^{-12}C^2N^{-1}m^{-2})(4\pi\times10^{-7}Ns^2C^{-2})}}$$

$$= 2.998\times10^8 \text{ m s}^{-1}$$

Also, magnitudes of E- & B-fields are related: E/B = c