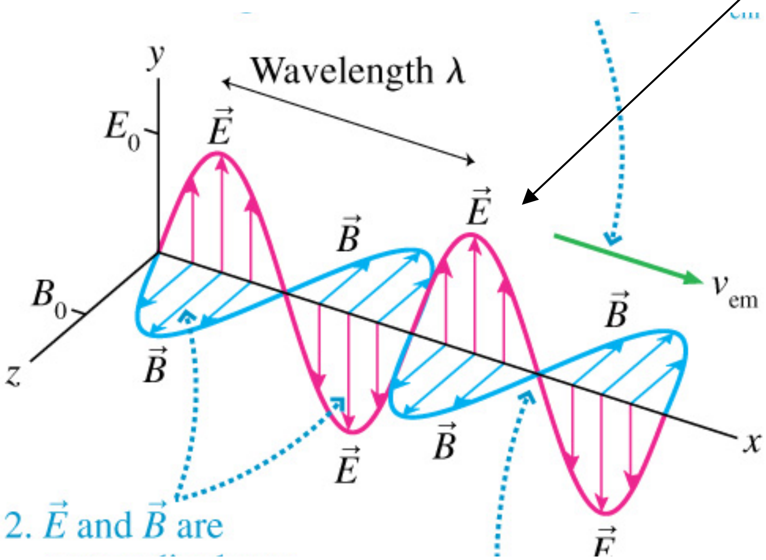
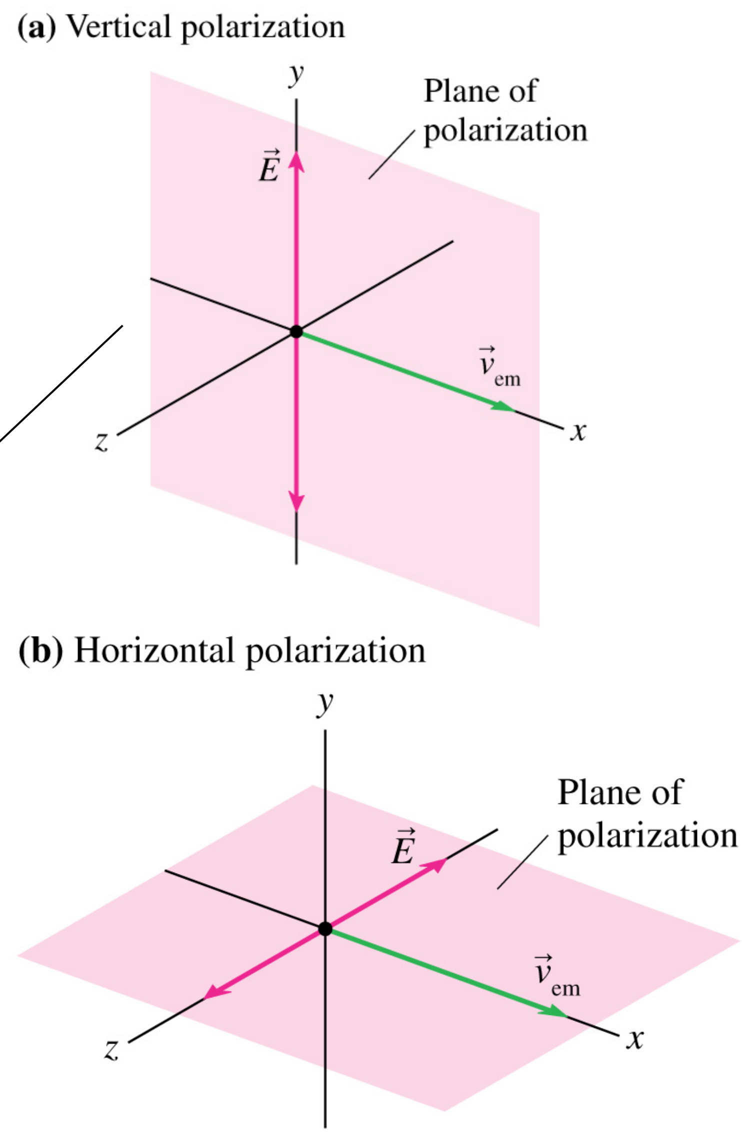
# Physics 294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **hand-in problem for Wed Mar. 23: 34.60**
  - **Note I revised Homework assignment 9 (due 3/23) adding some problems that were due a week later**
- Quizzes by iclicker (sometimes hand-written)
- 2nd exam next Thursday
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

# Polarization

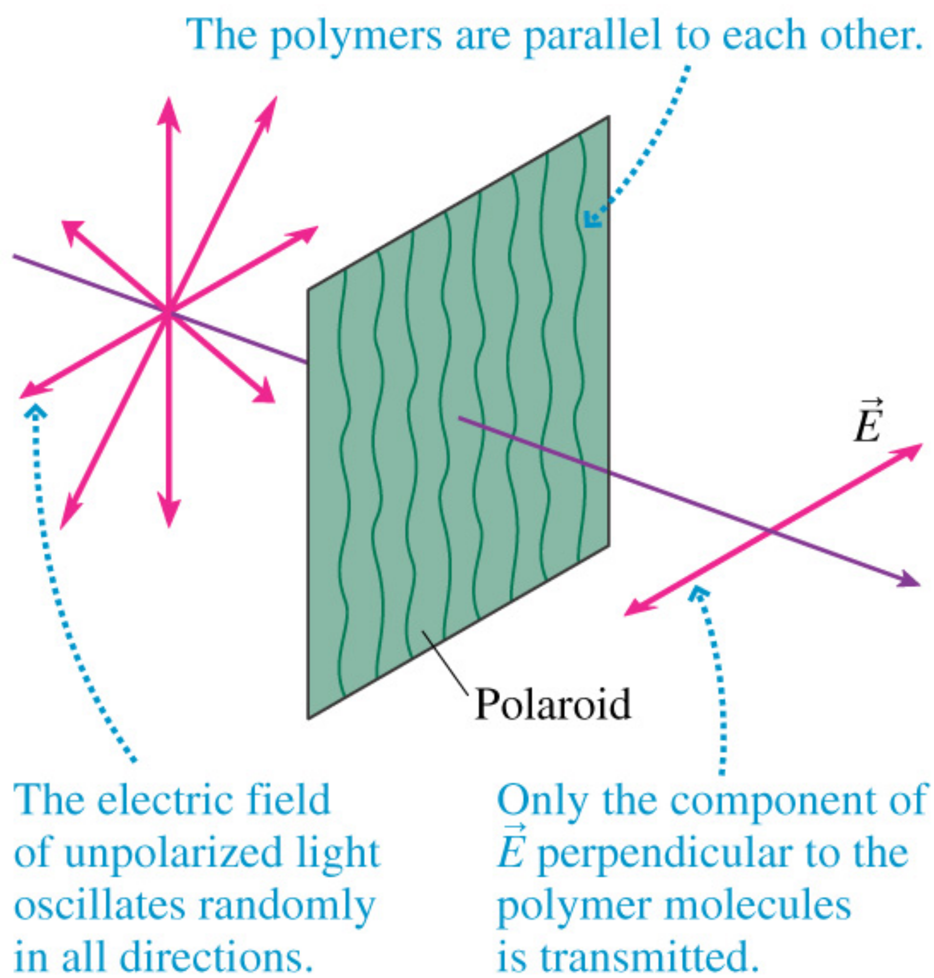
- the plane containing the electric field vector and the Poynting vector S is called the plane of polarization of the EM wave



# Polarizing filter

- Ordinary electromagnetic waves are unpolarized
  - the electric field vectors for each wave are random
- A polarizing filter lets in only those EM waves with a polarization in a particular direction
  - polymer chains are treated to make them conducting
  - electrons absorb energy from EM waves whose electric fields oscillate in the direction of the chains



# Polarization

- Electric field from EM wave can be decomposed into components along x (perpendicular to polarization axis) and y directions (parallel to)

$$E_{incident} = E_o \sin\theta\, \hat{i} + E_o \cos\theta\, \hat{j}$$

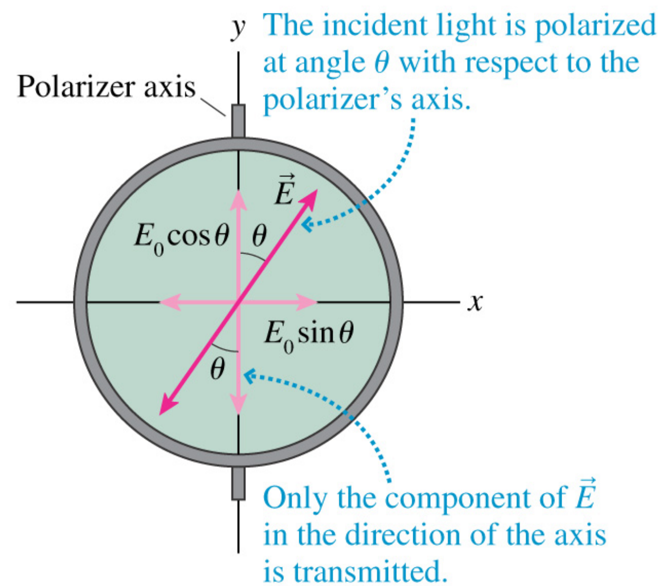
- If the filter is 100% efficient, then only component perpendicular to polarization axis is transmitted

$$E_{transmitted} = E_o \cos\theta\, \hat{j}$$

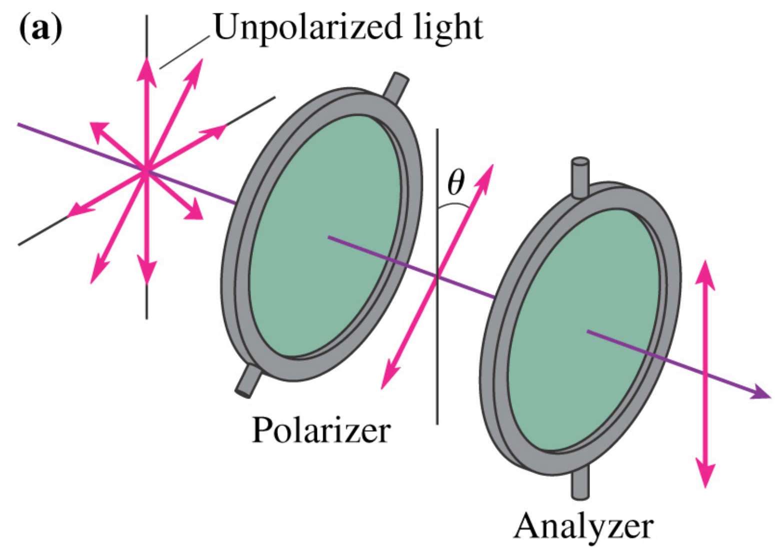
- The intensity of light depends on the square of the electric field so for initial polarized light

$$I_{transmitted} = I_o \cos^2\theta$$

(Malus' law)




(a)

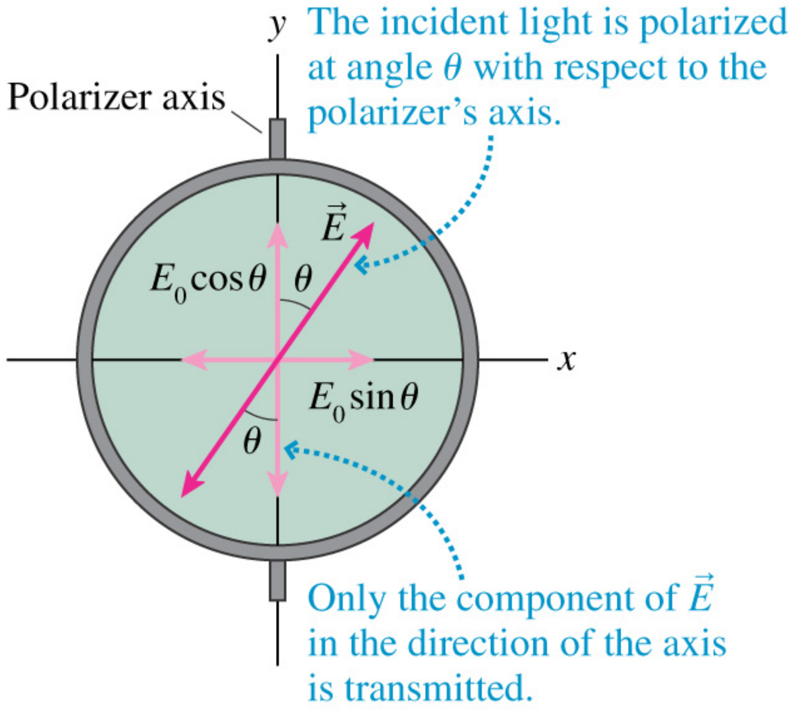


# Polarization

- If the light is initially unpolarized, then the direction of the electric field is random, and the average value of $\cos^2\theta$ is 0.5

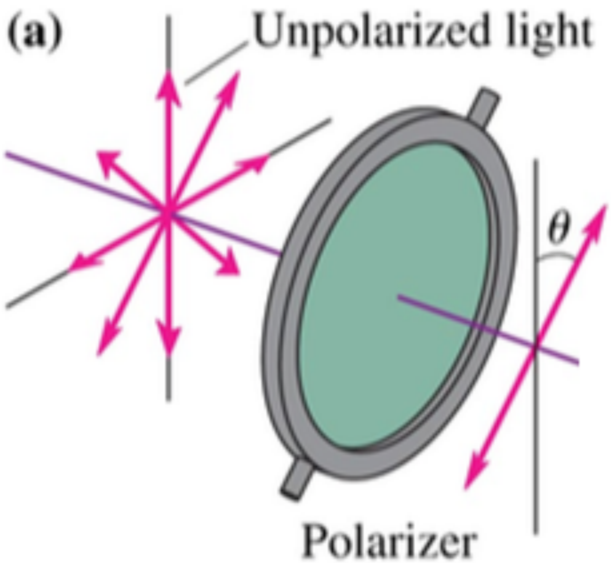
$$I_{transmitted} = I_o \overline{\cos^2\theta}$$

$$I_{transmitted} = I_o \left(\frac{1}{2}\right)$$



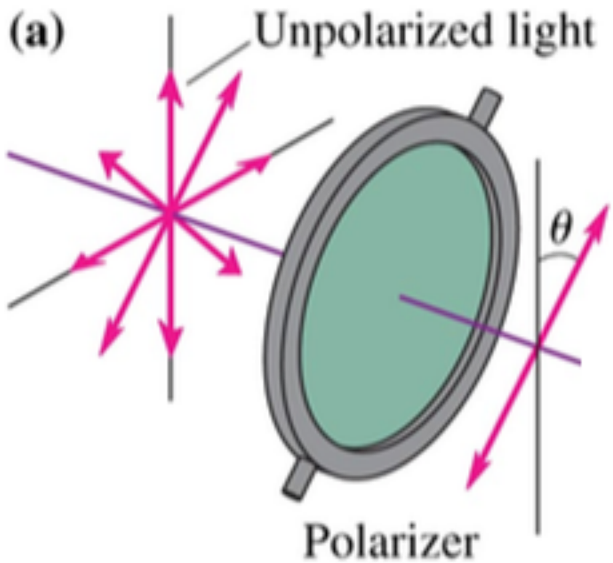
# iclicker question

Unpolarized light is incident on a polarizing filter with an intensity of 50 W/m$^2$. What is the intensity of the light after it passes through the polarizer?




A. 10 W/m$^2$
B. 25 W/m$^2$
C. 50 W/m$^2$
D. 100 W/m$^2$

Unpolarized light is incident on a polarizing filter with an intensity of 50 $W/m^2$. What is the intensity of the light after it passes through the polarizer?



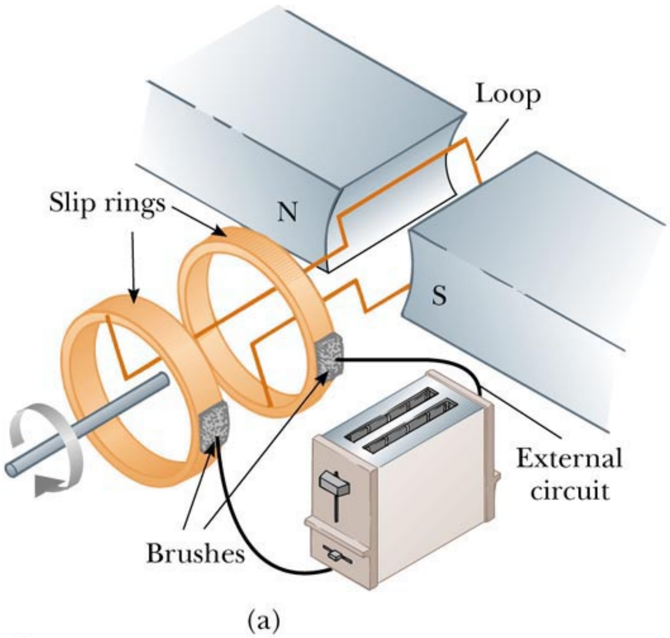

$$I_{transmitted} = \frac{1}{2} I_{unpolarized}$$

A. 10 $W/m^2$
B. 25 $W/m^2$
C. 50 $W/m^2$
D. 100 $W/m^2$

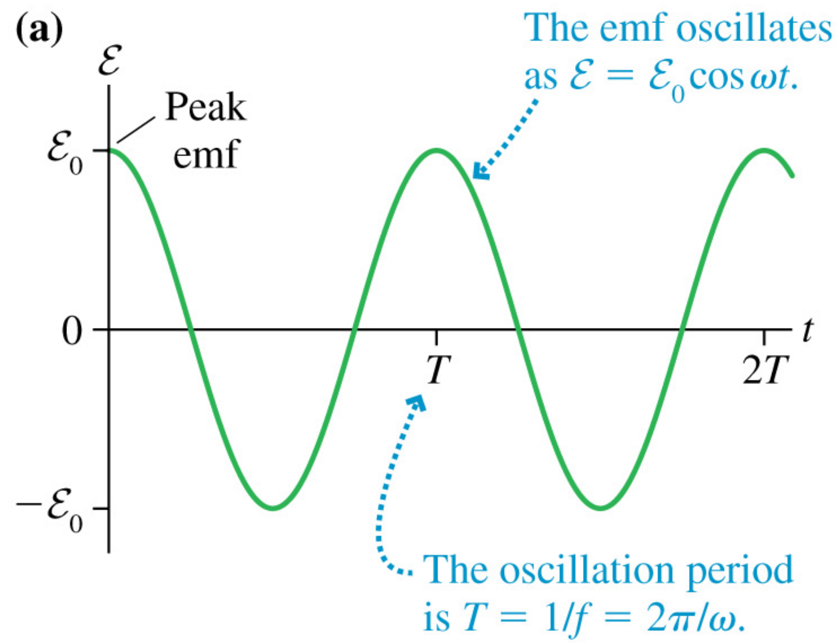
**Answer: B, When unpolarized light strikes a polarizer you lose half of the intensity. $I_{transmitted} = ½ * 50 = 25\ W/m^2$.**

# AC circuits

- We saw earlier that an electric generator produced an alternating voltage and current

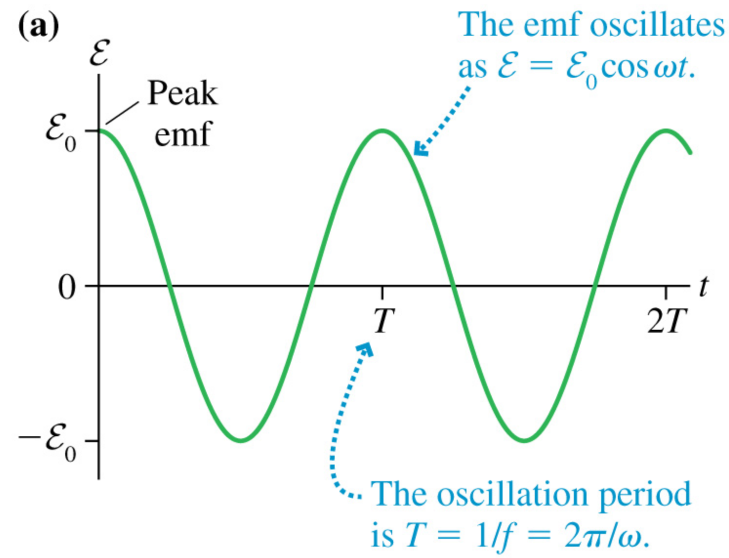






# Phasers

- It is useful to represent AC voltages and currents with phasers



# Phasers

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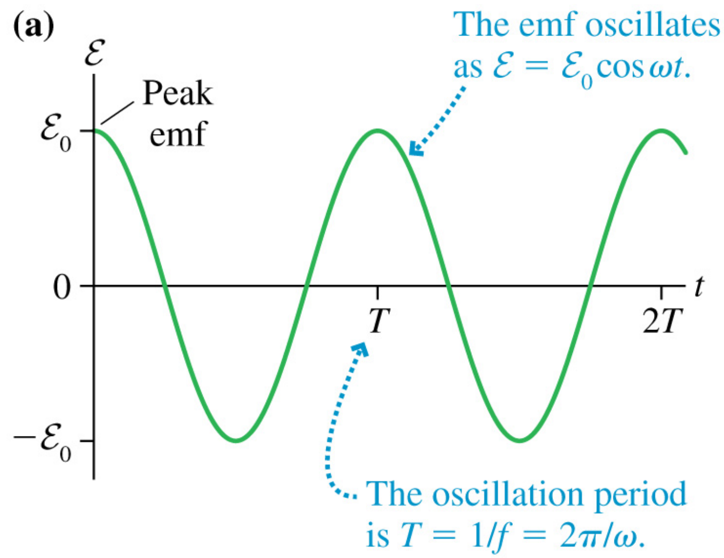
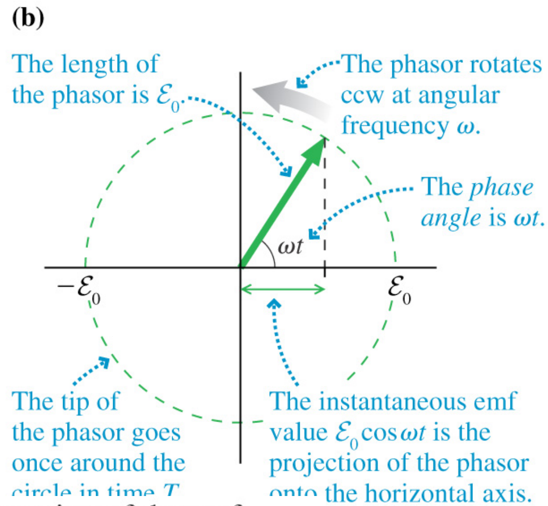
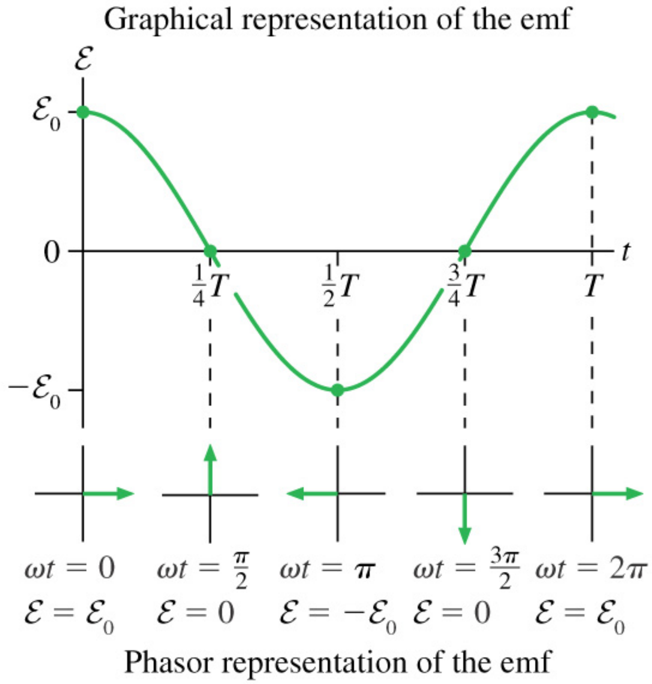



# Phasors

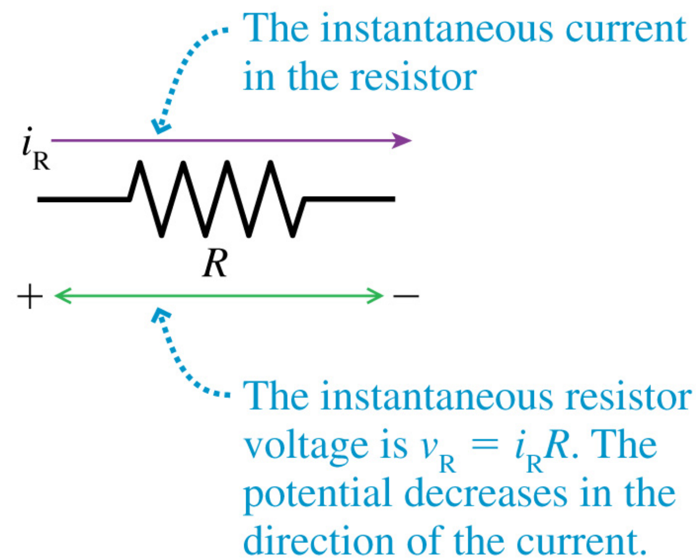
- Wrong spelling…sorry
- A phasor is a vector that rotates counterclockwise around the origin with an angular frequency $\omega$
  - the instantaneous vaue of a quantity (voltage, current) is the projection of the phasor on the horizontal axis
  - sometimes it's defined with respect to the vertical axis, but that just causes a phase change
  - $\omega t$ is called the phase angle



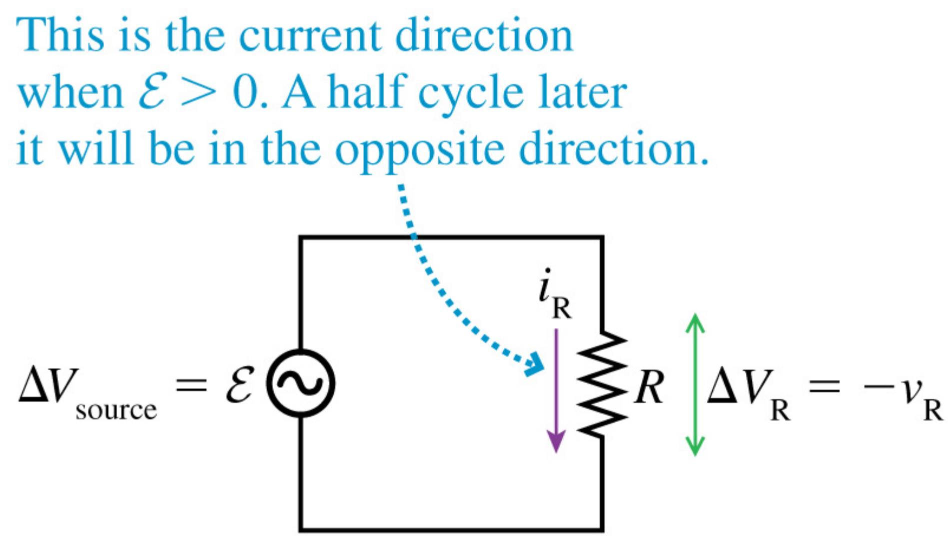
# AC circuits with resistors

- Suppose I have a circuit consisting of an AC generator and a resistor
- I want to look at the currents and voltages in the circuits
- I do it the same way I did it for DC circuits, using Kirchoff's laws




$$\sum \Delta V = \Delta V_{source} + \Delta V_R = \varepsilon - v_R = 0$$

$$v_R = \varepsilon = \varepsilon \cos \omega t$$




- The voltage of the generator appears across the resistor, in phase

# AC circuits with resistors

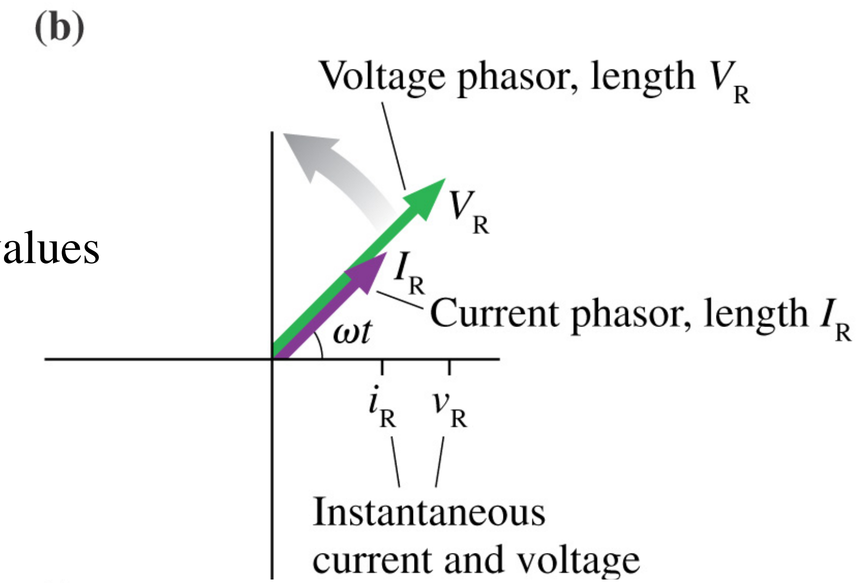
- So I can write the voltage and current as

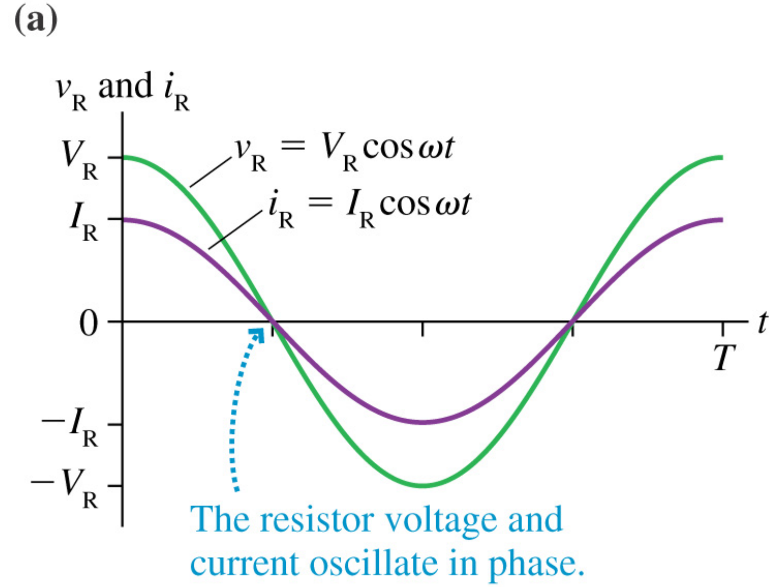
instan-taneous values → maximum values

$$v_R = V_R \cos\omega t$$

$$i_R = \frac{v_R}{R} = \frac{V_R \cos\omega t}{R} = I_R \cos\omega t$$

- Note that the voltage and current are in phase with each other and they have the same angular velocity ω



# AC circuits with capacitors

- We can write the voltage across the capacitor as

$$v_c = V_c \cos \omega t$$

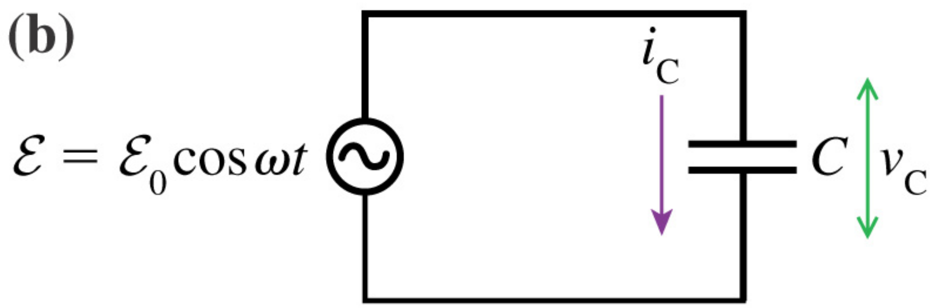
$V_c \rightarrow \varepsilon_o$

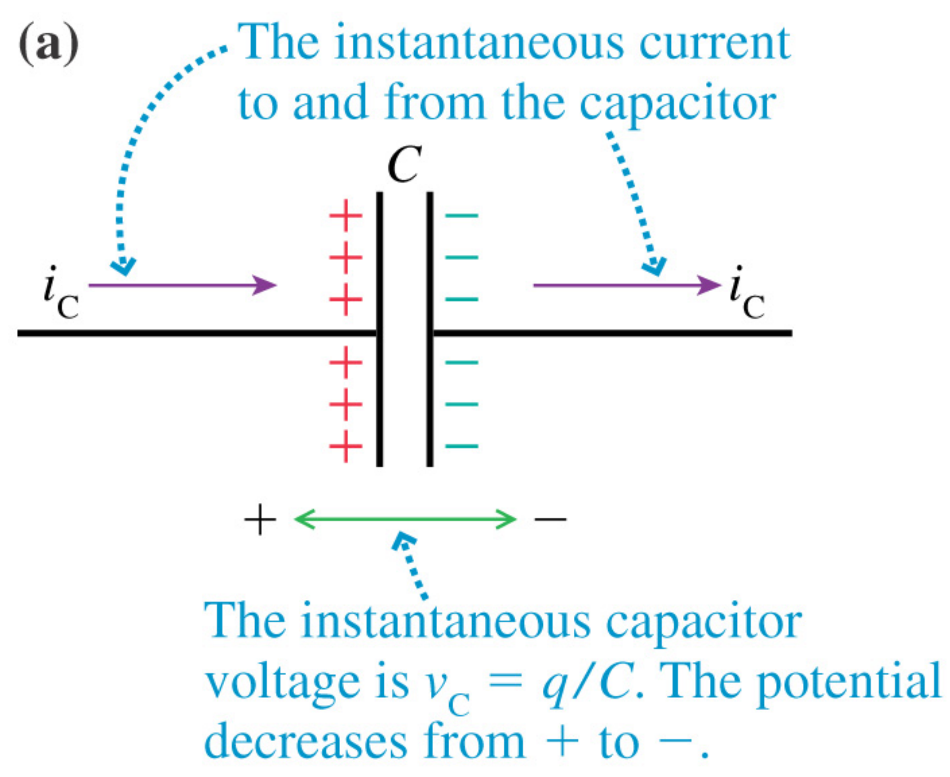
- The charge on the capacitor is

$$q = C v_c = C V_c \cos \omega t$$

- The current is

$$i = \frac{dq}{dt} = -\omega C V_c \sin \omega t$$



# AC circuits with resistors

- So I can write the voltage and current as

instan-taneous values → $v_R = V_R \cos \omega t$ ← maximum values

$$i_R = \frac{v_R}{R} = \frac{V_R \cos \omega t}{R} = I_R \cos \omega t$$

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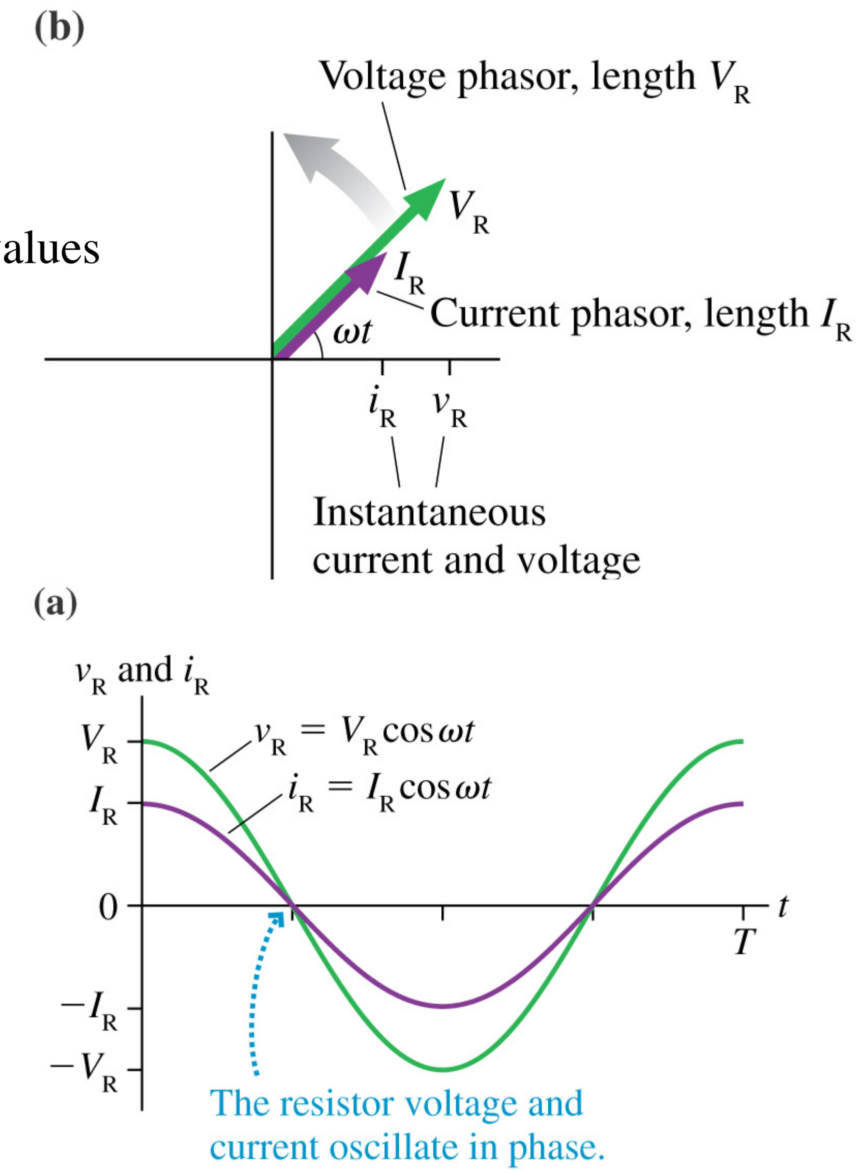

# AC circuits with capacitors

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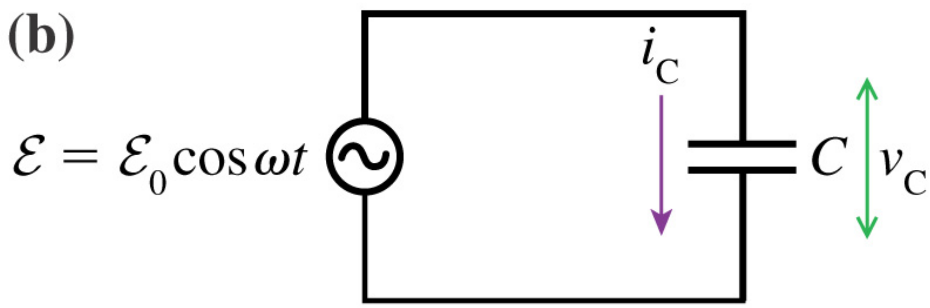
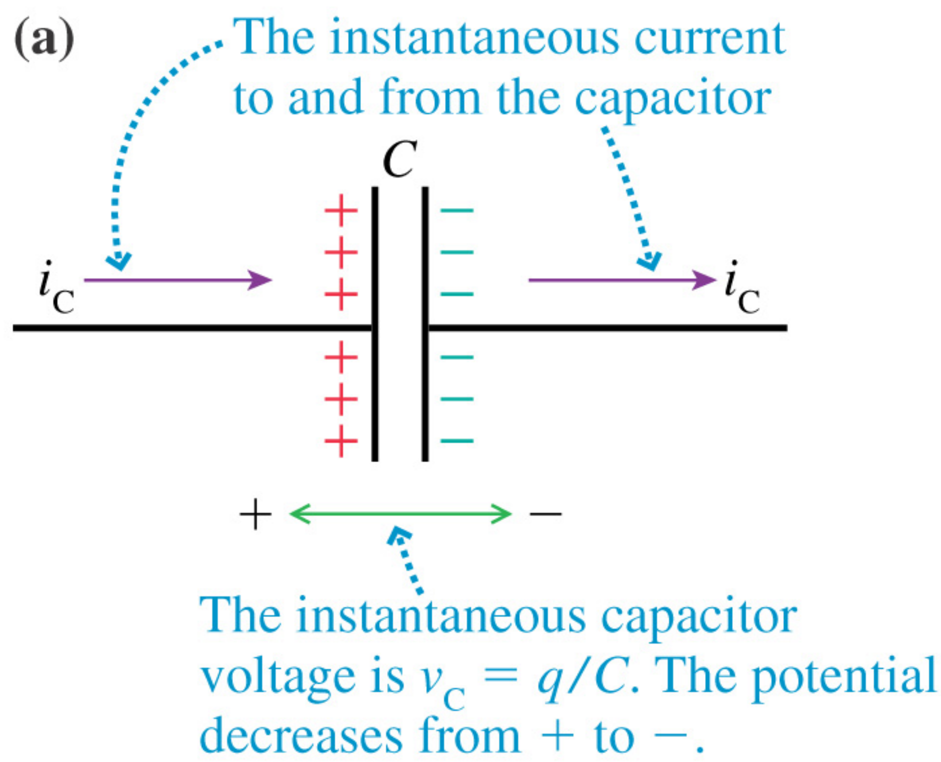


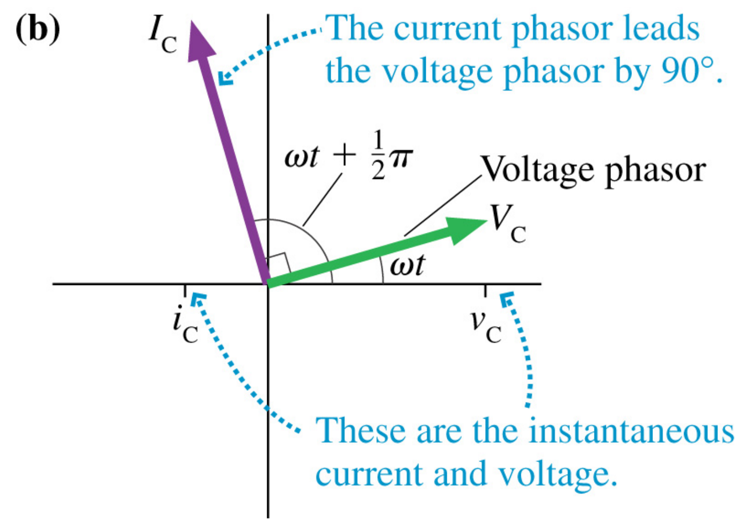



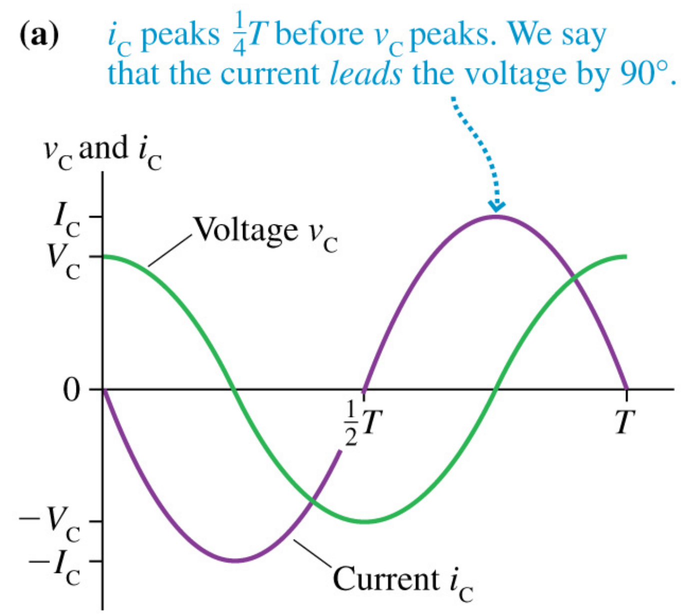
# AC circuits with capacitors

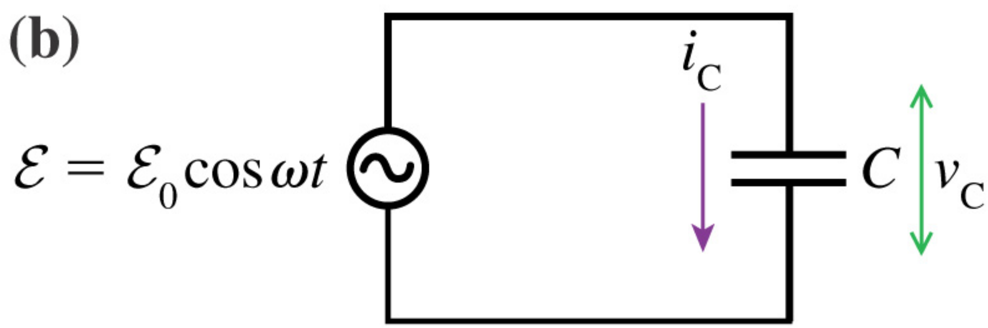
- I can also write

$$i = \omega C V_c \cos\left(\omega t + \frac{\pi}{2}\right)$$

- The AC current through a capacitor leads the voltage by 90°



# AC circuits with capacitors

- We can define the capacitive reactance $X_c$ as

$$X_c = \frac{1}{\omega C}$$

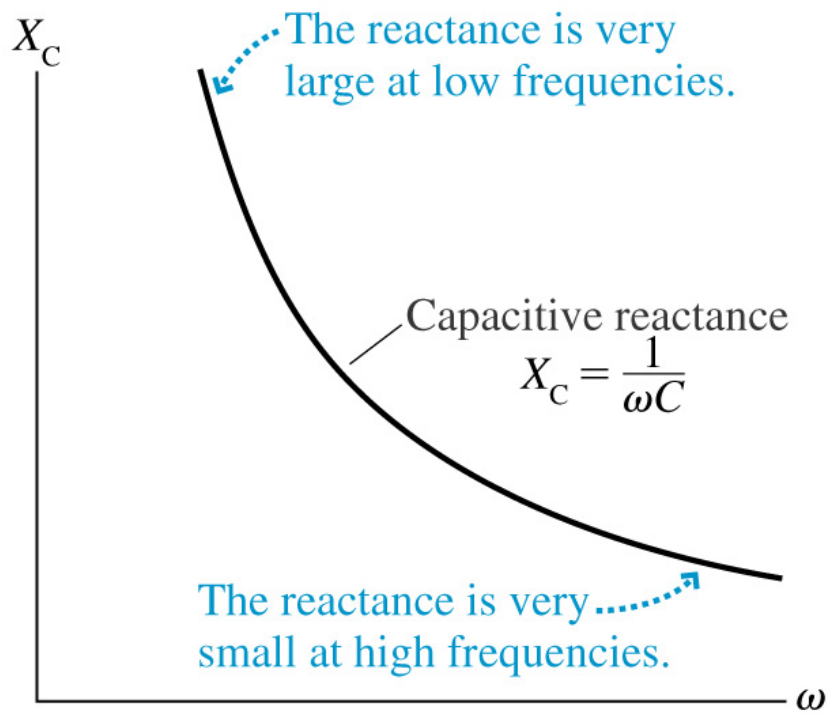
$$I_c = \frac{V_c}{X_c}$$

$$V_c = I_c X_c$$

- Note that the reactance relates the peak voltage and the peak current and not the instantaneous voltage and current

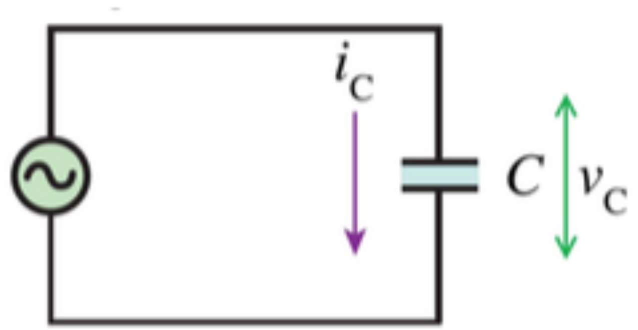
$$v_c \neq i_c X_c$$

- The unit of reactance is Ω



# iclicker question

- A capacitor is attached to an AC voltage source. How could you double the current in the circuit?




A. Double the capacitance.
B. Double the voltage.
C. Double the frequency.
D. All of the above.

$I_C =$

# iclicker question

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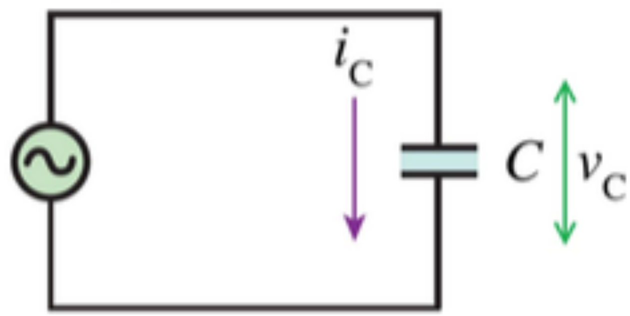



$$I_C = \frac{V_C}{X_C}$$

$$X_C = \frac{1}{\omega C}$$

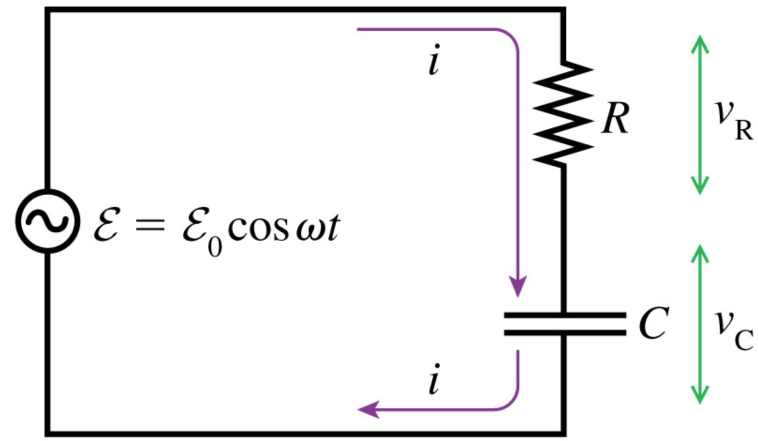
A. Double the capacitance.
B. Double the voltage.
C. Double the frequency.
D. All of the above.

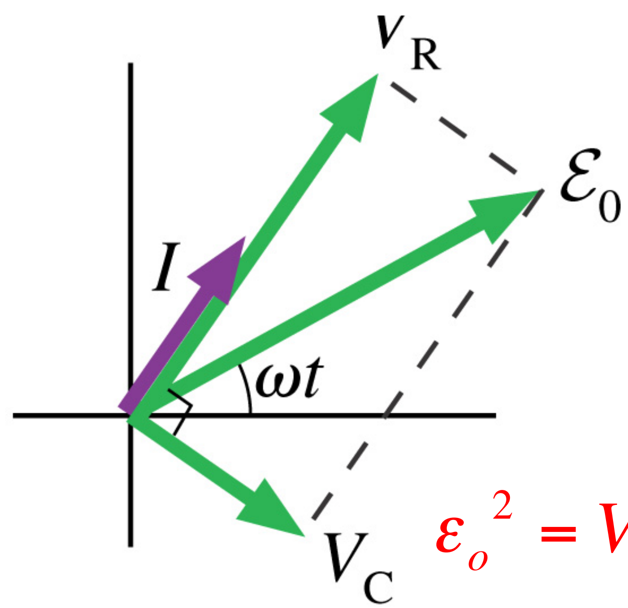
$$I_C = \frac{V_C}{X_C} = \omega C V_C$$

**Answer: D, The capacitive reactance, $X_C$, is $(2\pi fC)^{-1}$ so doubling the capacitance OR the voltage OR the frequency would all work.**

# Circuits with resistors and capacitors

- If the frequency is low, then we expect $X_C$ to be larger than R, while if the frequency is high we expect $X_C$ to be smaller than R
- For the phasor for this circuit, I and $V_R$ are in phase, $V_C$ is 90° behind I
- $v_R+v_C=\varepsilon$ (at any point in time), so draw the emf phasor as the vector sum of $V_R$ and $V_C$
  - $\varepsilon=\varepsilon_o\cos\omega t$




$$\varepsilon_o^{\ 2} = V_R^{\ 2} + V_C^{\ 2}$$

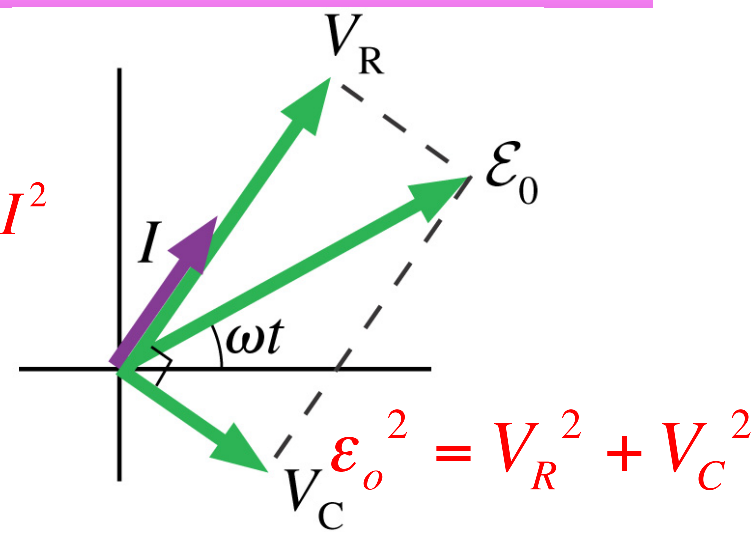
peak values

# Circuits with resistors and capacitors

- Calculate the current

$$\varepsilon_o^{\,2} = V_R^{\,2} + V_C^{\,2} = (IR)^2 + (IX_C)^2 = (R^2 + X_C^{\,2})I^2$$

$$= \left( R^2 + \frac{1}{\omega^2 C^2} \right) I^2$$



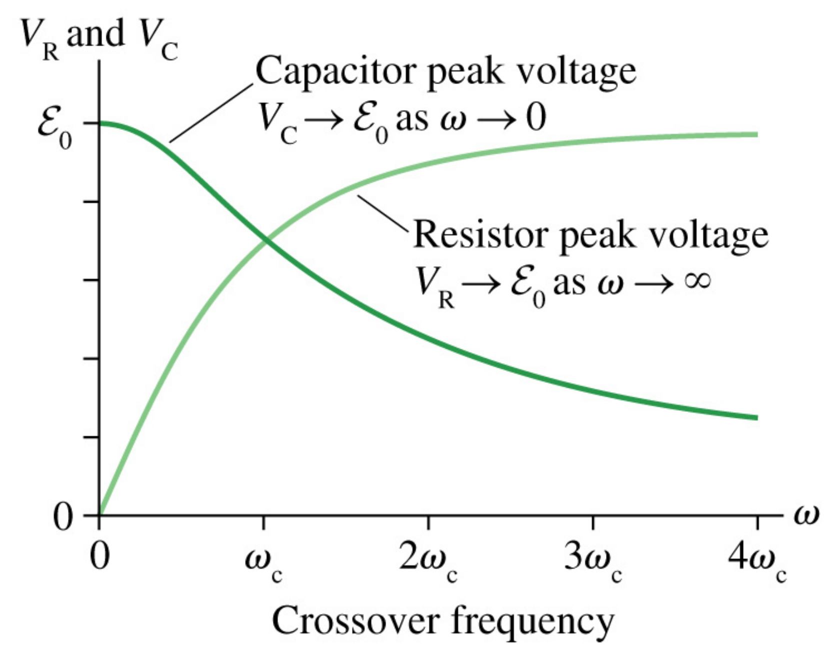

- Thus, I can write the peak current as

$$I = \frac{\varepsilon_o}{\sqrt{R^2 + X_C^{\,2}}} = \frac{\varepsilon_o}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}}$$

- The peak voltages are

$$V_R = IR = \frac{\varepsilon_o R}{\sqrt{R^2 + X_C^{\,2}}} = \frac{\varepsilon_o R}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}}$$

$$V_C = IX_C = \frac{\varepsilon_o X_C}{\sqrt{R^2 + X_C^{\,2}}} = \frac{\varepsilon_o X_C}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}}$$



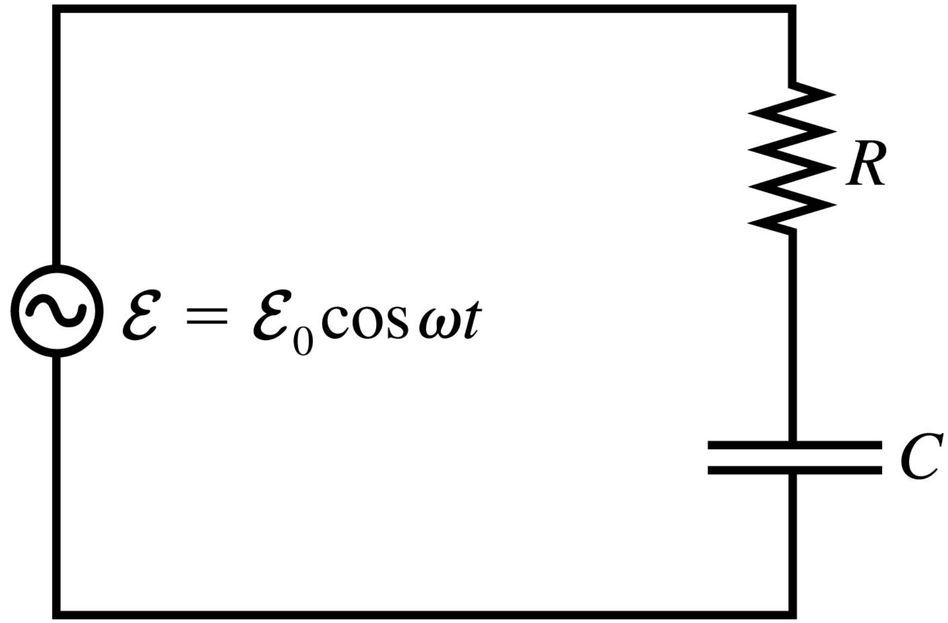
# iclicker

Does $V_R + V_C = \ _0$?

A. Yes.

B. No.

C. Can't tell without knowing $\omega$.



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Does $V_R + V_C = \ _0$?

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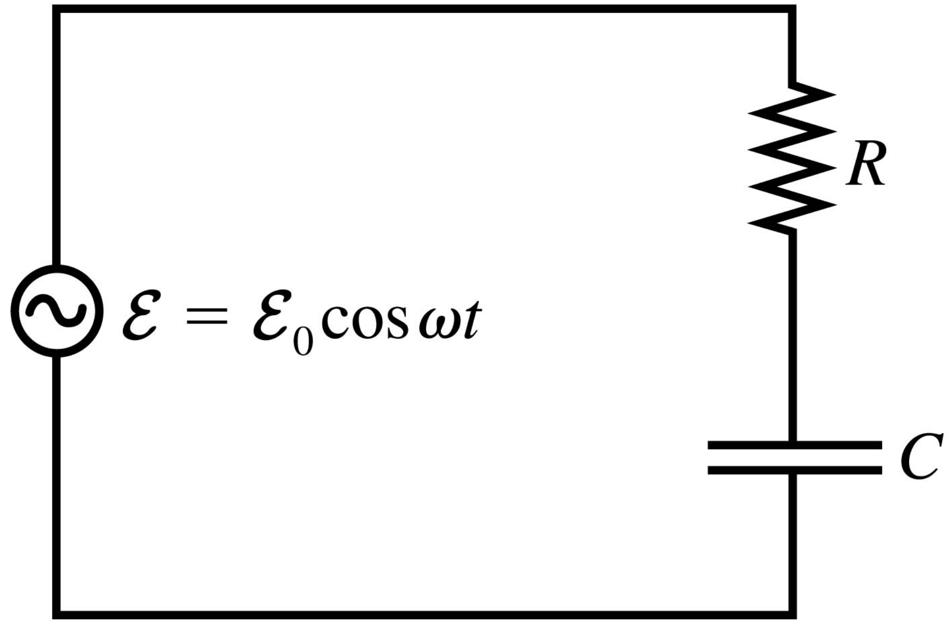
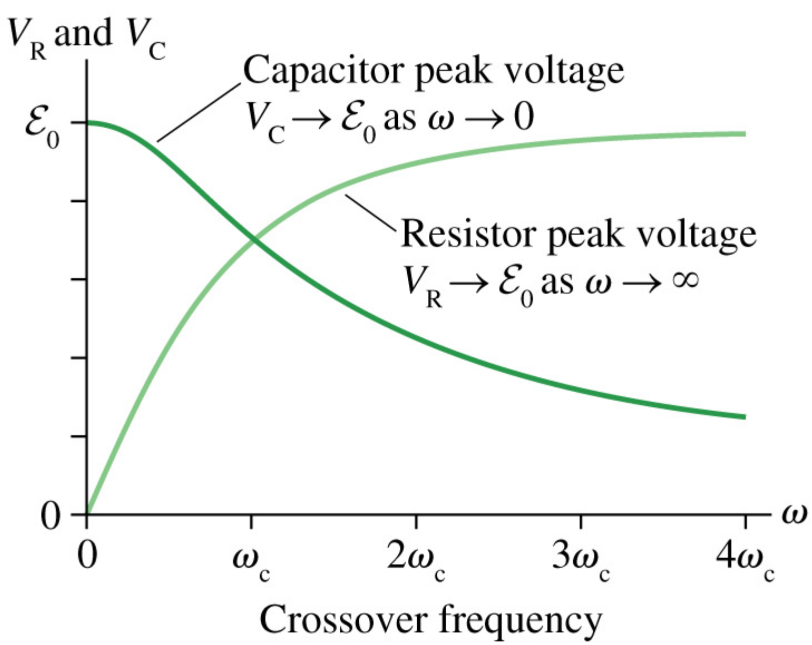



Instantaneous voltages add.

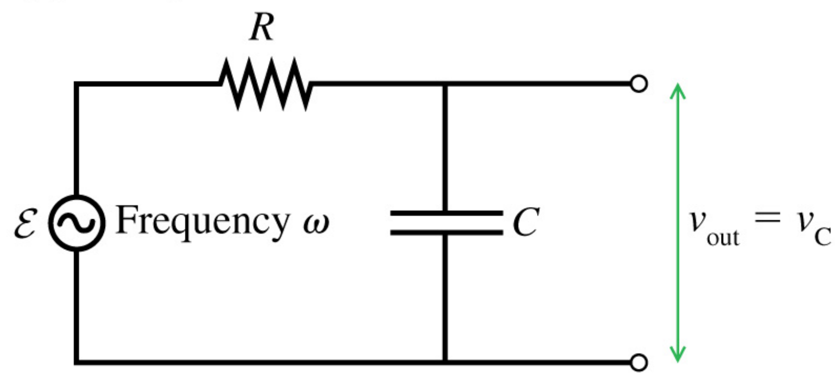
Peak voltages don't because the voltages are not in phase.

# Filters

- A low pass filter transmits a signal with a low frequency but blocks a signal with a high frequency
- And vice versa for a high pass filter

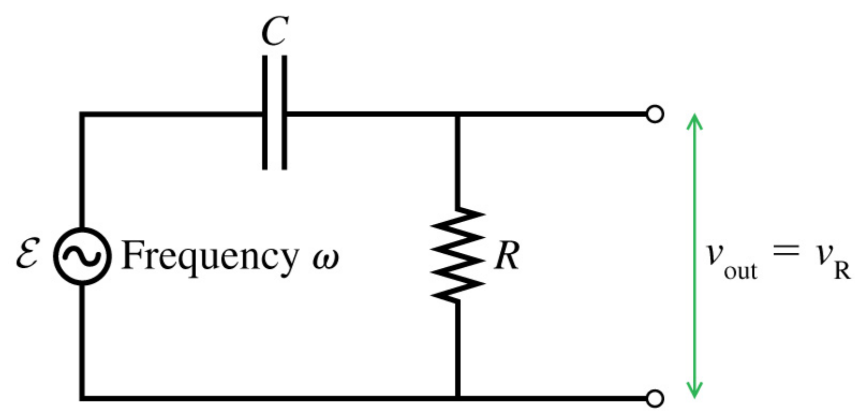



**(a)** Low-pass filter




Transmits frequencies $\omega < \omega_c$ and blocks frequencies $\omega > \omega_c$.

**(b)** High-pass filter




Transmits frequencies $\omega > \omega_c$ and blocks frequencies $\omega < \omega_c$.