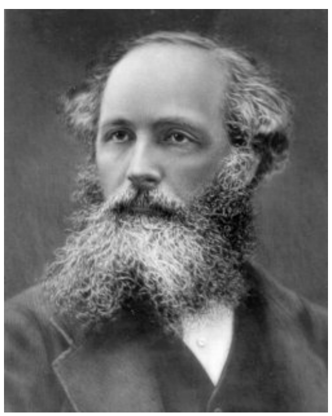
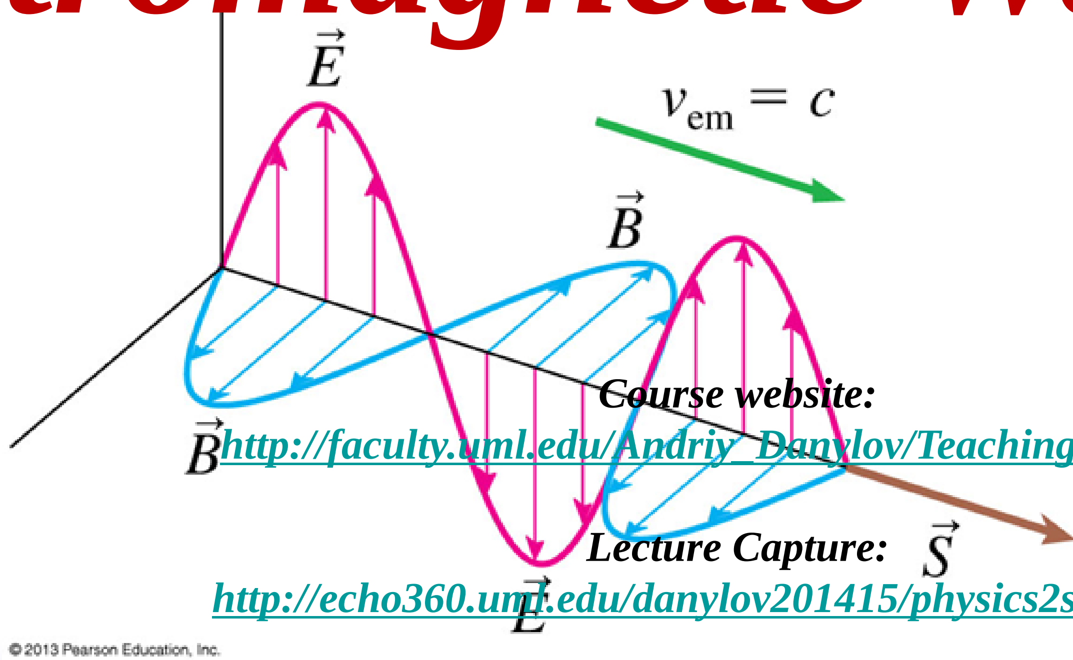
Lecture 19

University of Massachusetts
UMASS Lowell
Physics II
08.03.2015

Chapter 34

Electromagnetic Waves





Course website:
[***http://faculty.uml.edu/Andriy_Danylov/Teaching/PhysicsII***](http://faculty.uml.edu/Andriy_Danylov/Teaching/PhysicsII)

Lecture Capture:
[***http://echo360.uml.edu/danylov201415/physics2spring.html***](http://echo360.uml.edu/danylov201415/physics2spring.html)

Maxwell's Equations

Electric and magnetic fields are described by the four **Maxwell's Equations**:

the physical meaning

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\epsilon_0} \quad \text{Gauss's law}$$

An electric field is produced by a charge

$$\oint \vec{B} \cdot d\vec{A} = 0 \quad \text{Gauss's law for magnetism}$$

No magnetic monopoles

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_{\text{m}}}{dt} \quad \text{Faraday's law}$$

An electric field is produced by a changing magnetic field

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}} + \epsilon_0 \mu_0 \frac{d\Phi_{\text{e}}}{dt} \quad \text{Ampère-Maxwell law}$$

A magnetic field is produced by a changing electric field or by a current

In addition to Maxwell's equations, which describes the fields, a fifth equation is needed to tell us how matter responds to these fields:

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \quad \text{(Lorentz force law)}$$

ConcepTest 1 Induced fields

A loop with an increasing current produces an increasing magnetic field. Consider a copper loop, and next to it imagine a loop of air of equal size. In which of the loops will the induced electric field be greater?

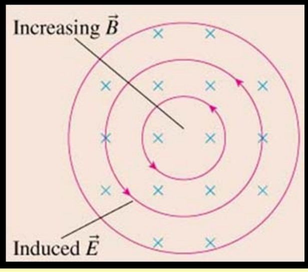
A) the plastic loop

B) the copper loop

C) electric field is same in both

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_m}{dt} \quad \text{Faraday's law}$$

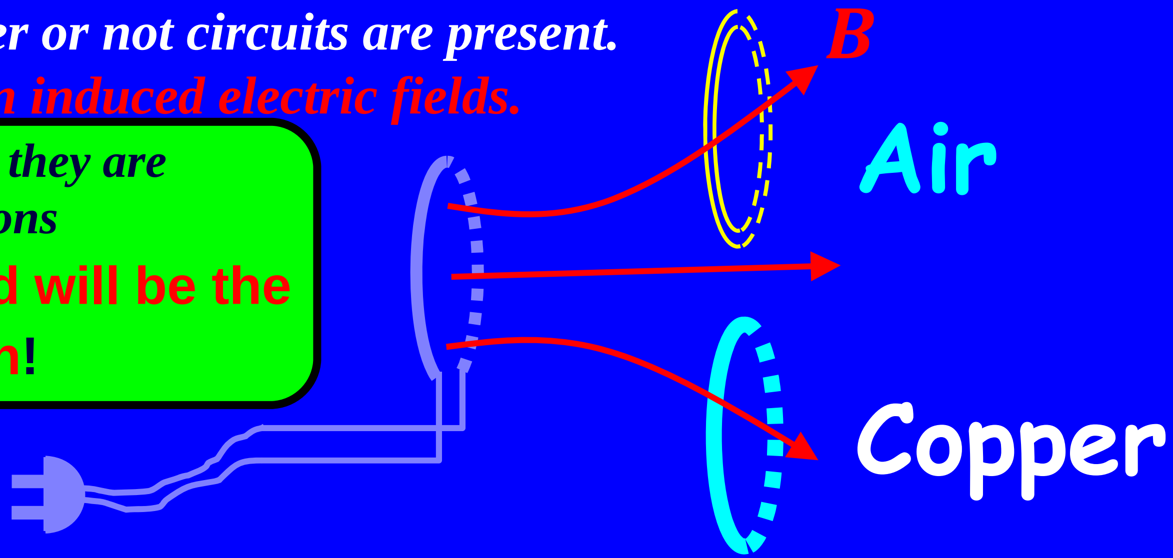
An electric field is produced by a changing magnetic field



(Lecture 17) Amazing thing of the induced el. field:
The conducting loop is not necessary.
The electric field arise whether or not circuits are present.
The space is filled with an induced electric fields.

Because of the symmetry, they are in the same conditions

The induced electric field will be the same in both!



ConcepTest 2 Induced current

In which of the loops is the induced current greater?

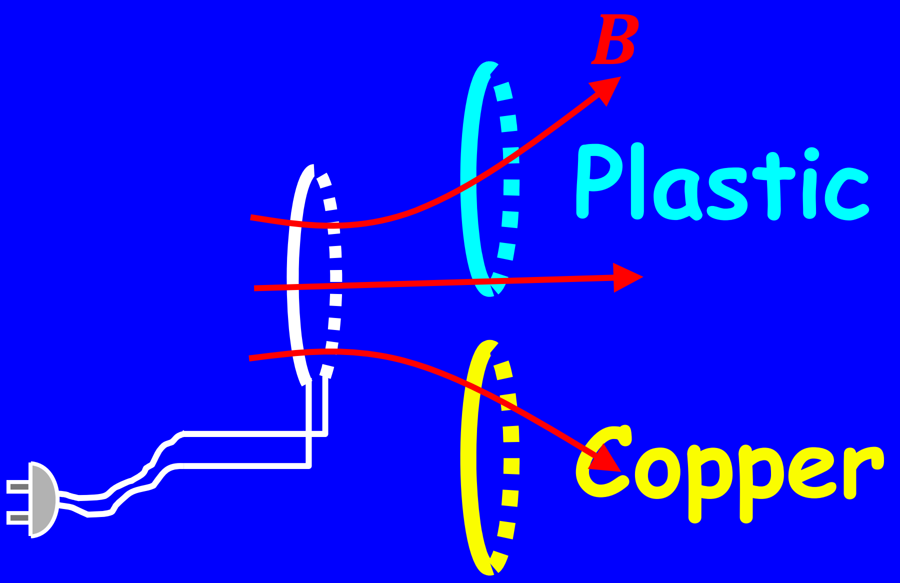
A) the plastic loop

B) the copper loop

C) current is same in both

Since the induced electric field will be the same in both loops!

Remember that $I = V / R$ (Ohm's law), and copper has smaller resistance, so the copper loop has the greater current.



Light is an electromagnetic wave

From Maxwell's equations we can get wave equations for E and B:

$$\frac{\partial^2 E_y}{\partial x^2} = \frac{1}{\mu_0 \varepsilon_0} \frac{\partial^2 E_y}{\partial t^2}$$

$$\frac{\partial^2 B_z}{\partial x^2} = \frac{1}{\mu_0 \varepsilon_0} \frac{\partial^2 B_z}{\partial t^2}$$

$= v^2$

Which can be solved:

Traveling waves:

$$E_y(x,t) = E_0 \sin(kx - \omega t)$$

$$B_z(x,t) = B_0 \sin(kx - \omega t)$$

It travels in +x direction

Amplitude

Wavenumber

Angular frequency

$$k = \frac{2\pi}{\lambda}$$

According to the wave theory, this factor is v^2

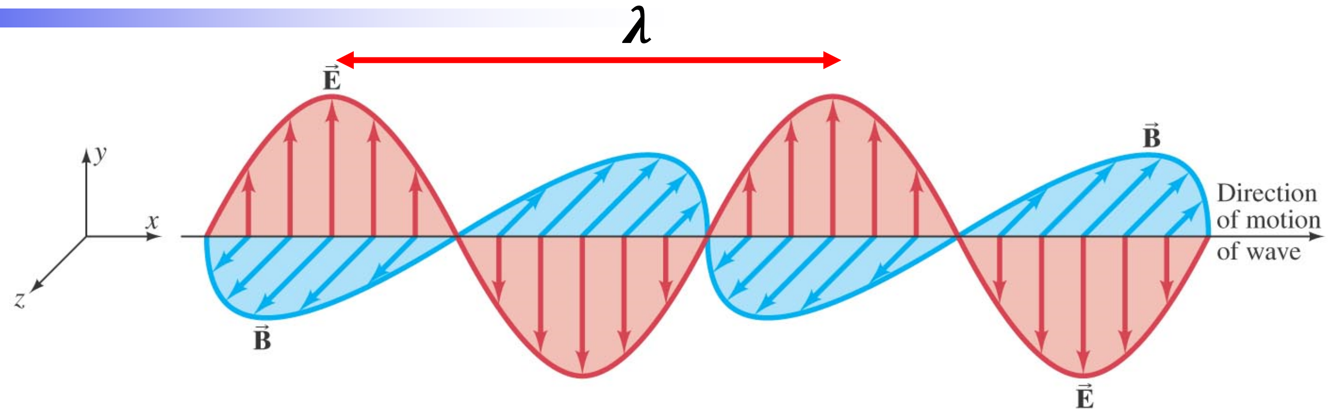
$$v = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \cdot 10^8 \frac{m}{s} = c \text{ (speed of light)}$$

The magnitude of this speed is 3.0×10^8 m/s – precisely equal to the measured speed of light.

Thus, it means that light is an electromagnetic wave (shocking conclusion)

Maxwell was the first to understand that
light is an oscillation of the electromagnetic field.

Properties of Electromagnetic Waves



The electric and magnetic waves are perpendicular to each other, and to the direction of propagation.

$$\vec{E} \perp \vec{B} \perp \vec{v}$$

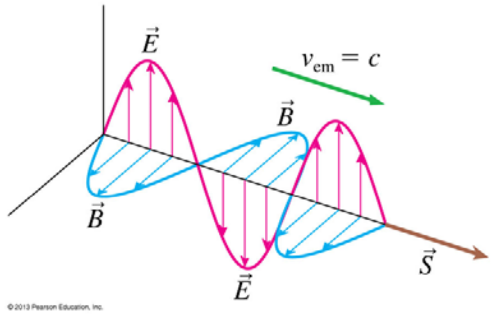
The oscillation amplitudes are related by: $E_0 = cB_0$

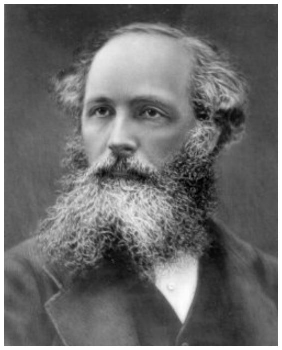
Here, *v* is the velocity of the wave: $v = c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ = 3.0 x 10^8 m/s

The frequency of an electromagnetic wave is related to its wavelength and to the speed of light:

$$c = \lambda f.$$

Electromagnetic Waves

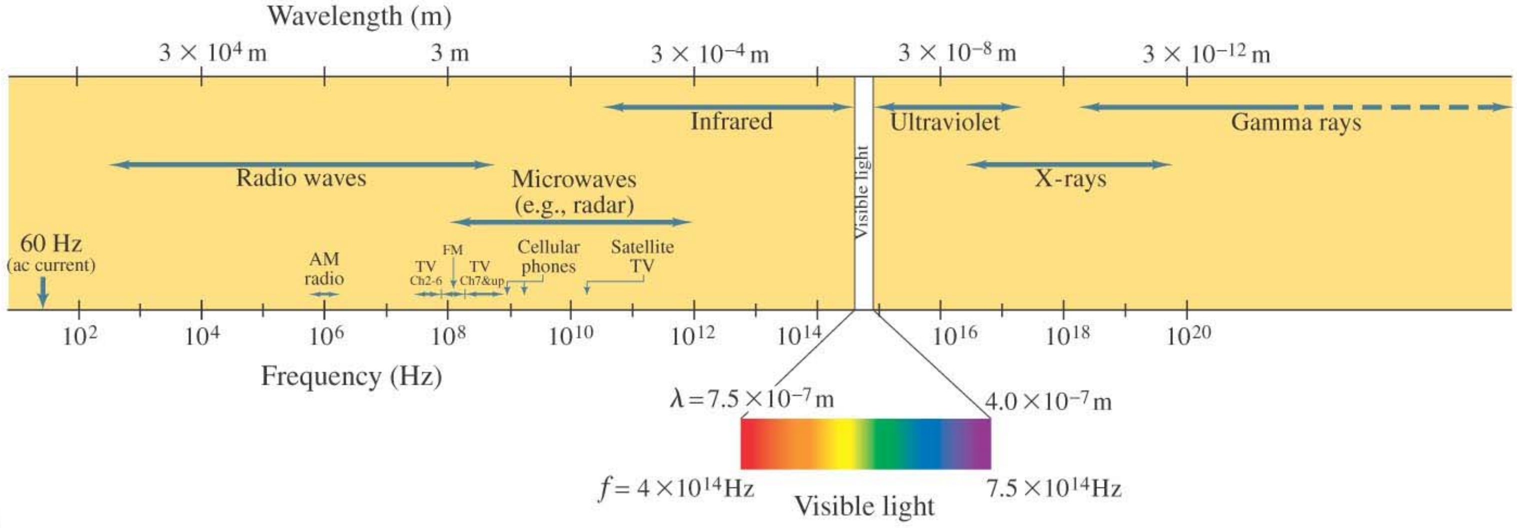




Since a changing electric field produces a magnetic field, and a changing magnetic field produces an electric field, they can propagate on their own.

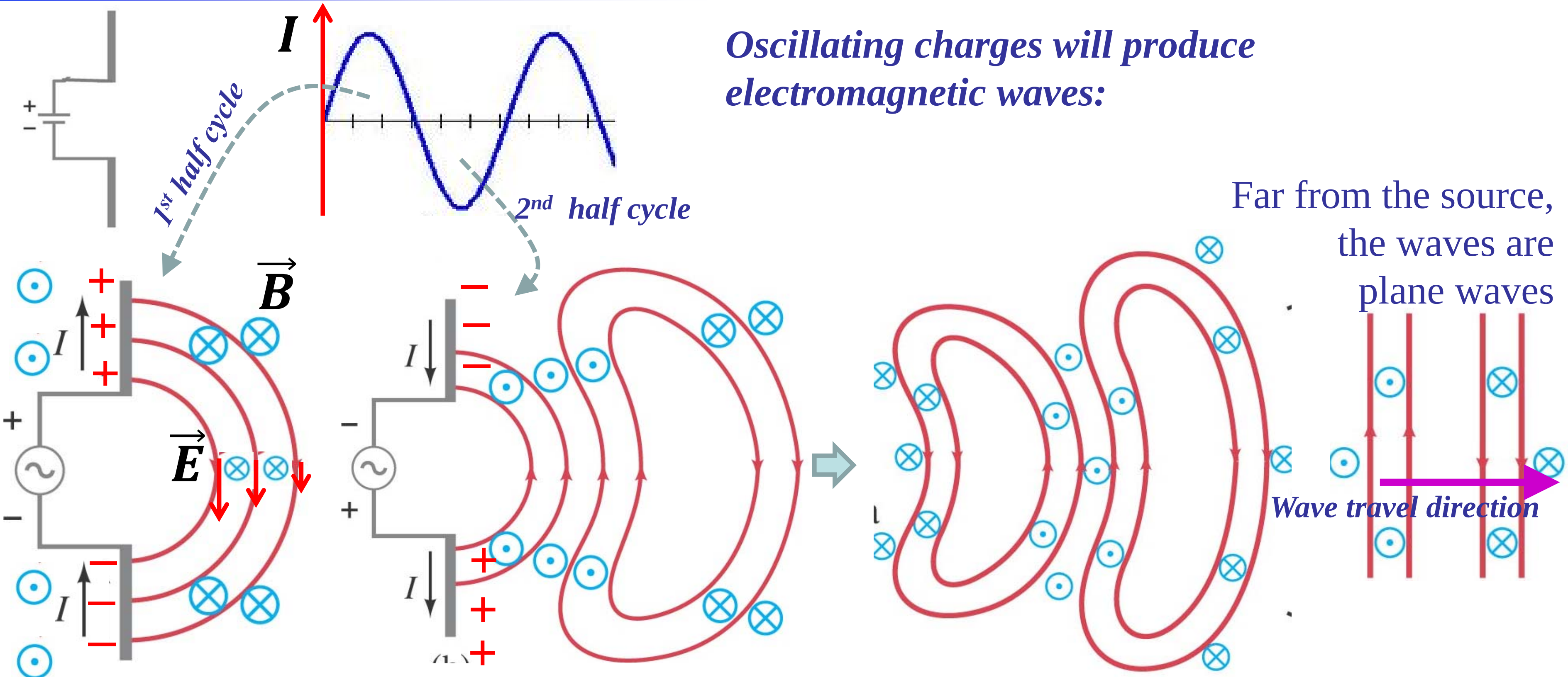
These propagating fields are called electromagnetic waves.

Maxwell was able to predict that electromagnetic waves can exist at any frequency, not just at the frequencies of visible light.

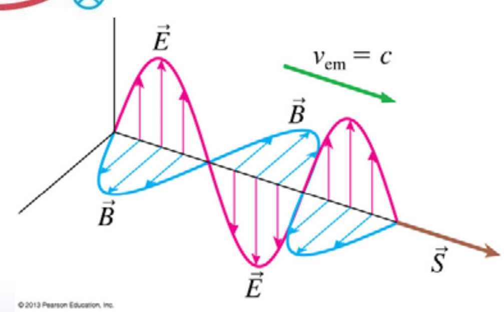


Production of Electromagnetic Waves

Oscillating charges will produce electromagnetic waves:



Far from the source, the waves are plane waves



ConcepTest 4 TV Antennas

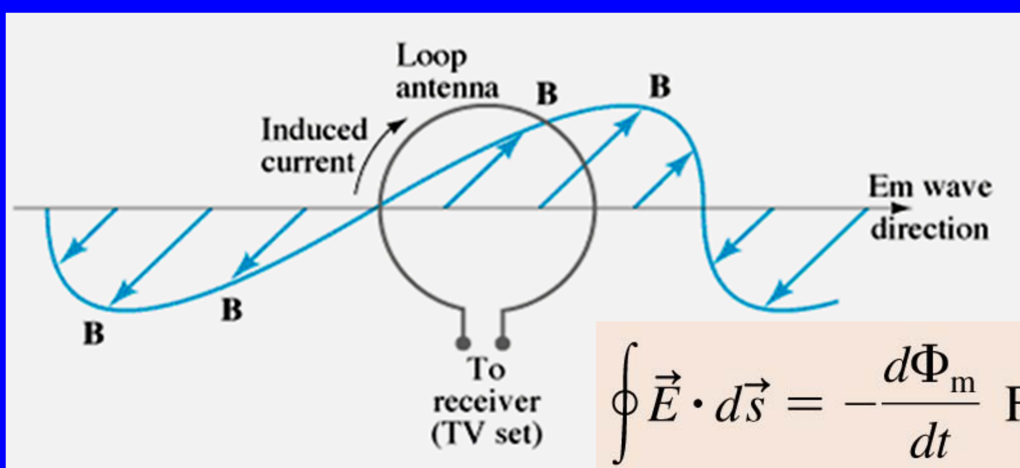
Before the days of cable, televisions often had two antennae on them, one straight and one circular. Which antenna picked up the magnetic oscillations?

A) the circular one

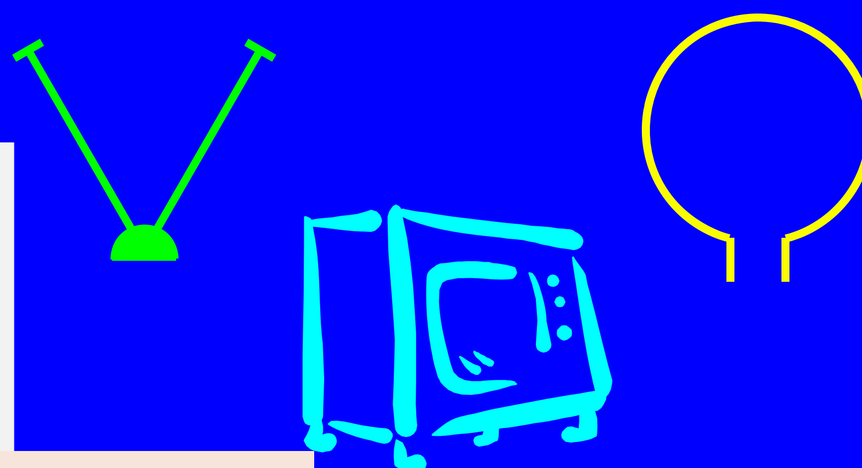
B) the straight one

C) both equally; they were straight and circular for different reasons

The varying *B* field in the loop means the flux is changing and therefore an emf is induced.



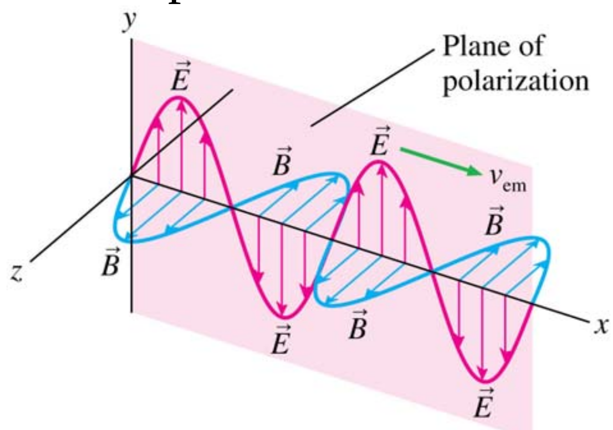
$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_m}{dt}$$ Faraday's law

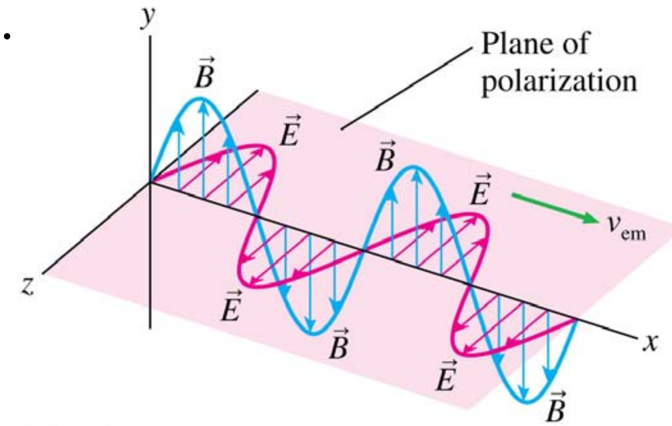


Polarization

Polarization

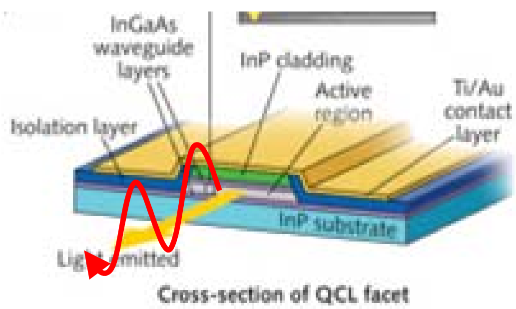
The plane of the electric field vector and the direction of propagation is called the **plane of polarization**.





The electric field in the figure oscillates vertically, so this wave is *vertically polarized*.

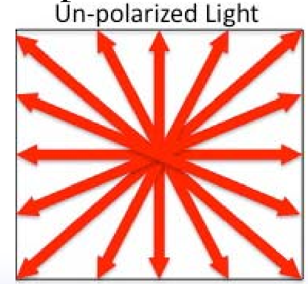
The electric field in the figure above is *horizontally polarized*.



Quantum cascade lasers emit *vertically polarized light*.

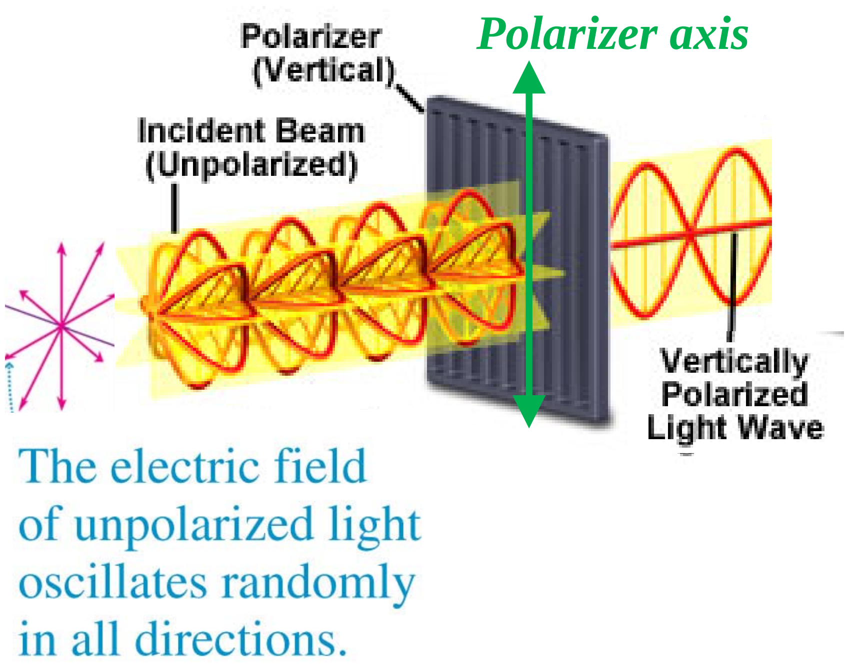
Most natural sources of light are unpolarized, emitting waves whose electric fields oscillate randomly with all possible orientations.

Un-polarized Light

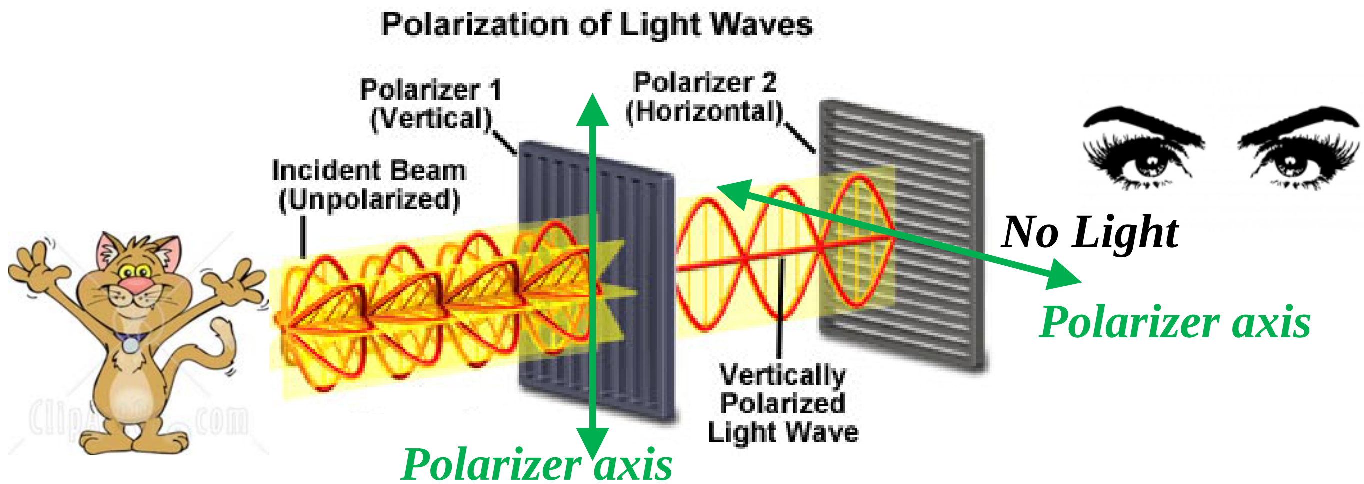


Polarizers

The most common way of artificially generating polarized visible light is to send unpolarized light through a *polarizing filter*.



Demo: *cat and crossed polarizers*



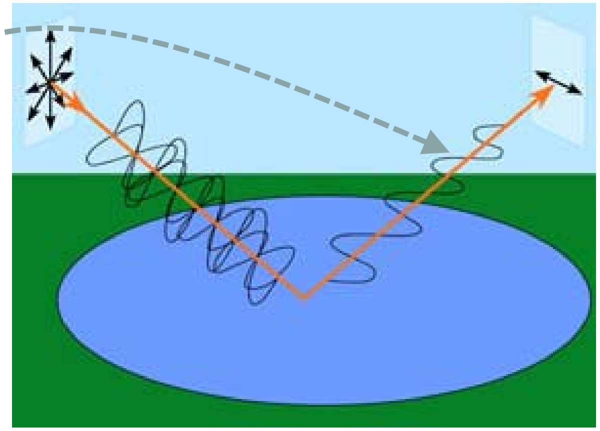
Two polarizing filters with perpendicular axes, called crossed polarizers, block all the light.

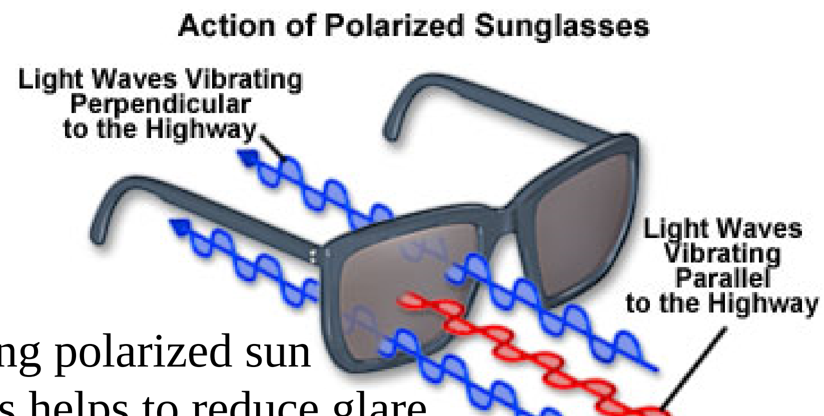
The polarizing direction of the first polarizer is oriented vertically to the incident beam so it will pass only the waves having vertical electric field vectors.

The wave passing through the first polarizer is subsequently blocked by the second polarizer, because this polarizer is oriented horizontally with respect to the electric field vector in the light wave.

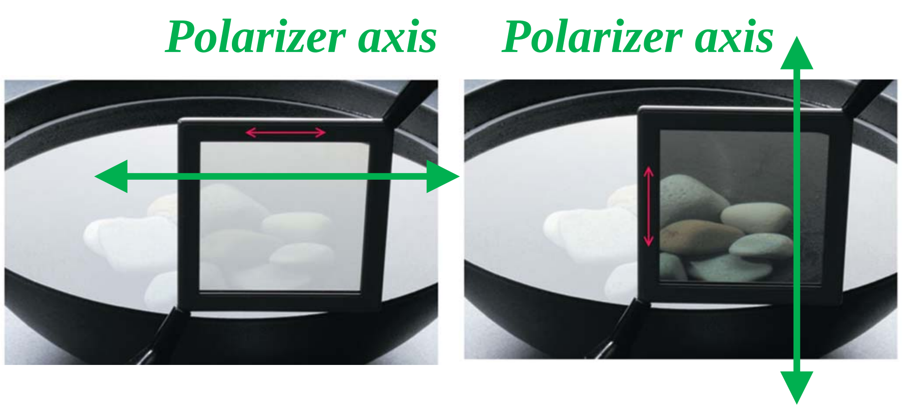
Polarizing Sunglasses

- *Glare*—the reflection of the sun and the skylight from roads, water and other horizontal surfaces—has a strong horizontal polarization.
- Vertically polarizing sunglasses can "cut glare" without affecting the main scene you wish to see.





Wearing polarized sun glasses helps to reduce glare



- This light is almost completely blocked by a vertical polarizing filter.

What you should read

Chapter 34 (Knight)

Sections

- ***34.5***
- ***34.6 (skip derivations of wave equations)***
- ***34.7***

Thank you

See you tomorrow