# Quantum Physics

## 2025

The Theory/Framework Of *Almost* Everything *Today*

But Most Likely NOT of Tomorrow

Yury Deshko

# Course Overview

## Course Structure And Goals

- **Part 1** : Mathematical Concepts And Tools.
- **Part 2** : Classical Physics.
- **Part 3** : Quantum Physics.

- Learn the language of quantum physics.
- Enhance the knowledge of classical physics.
- Develop modern quantum thinking.

We will focus on this one today.

# Focus Concepts

## Used in Classical And Quantum Physics

- Modes.
- Polarization.
- Spin

# Focus Concepts

## Used in Classical And Quantum Physics

- Modes.
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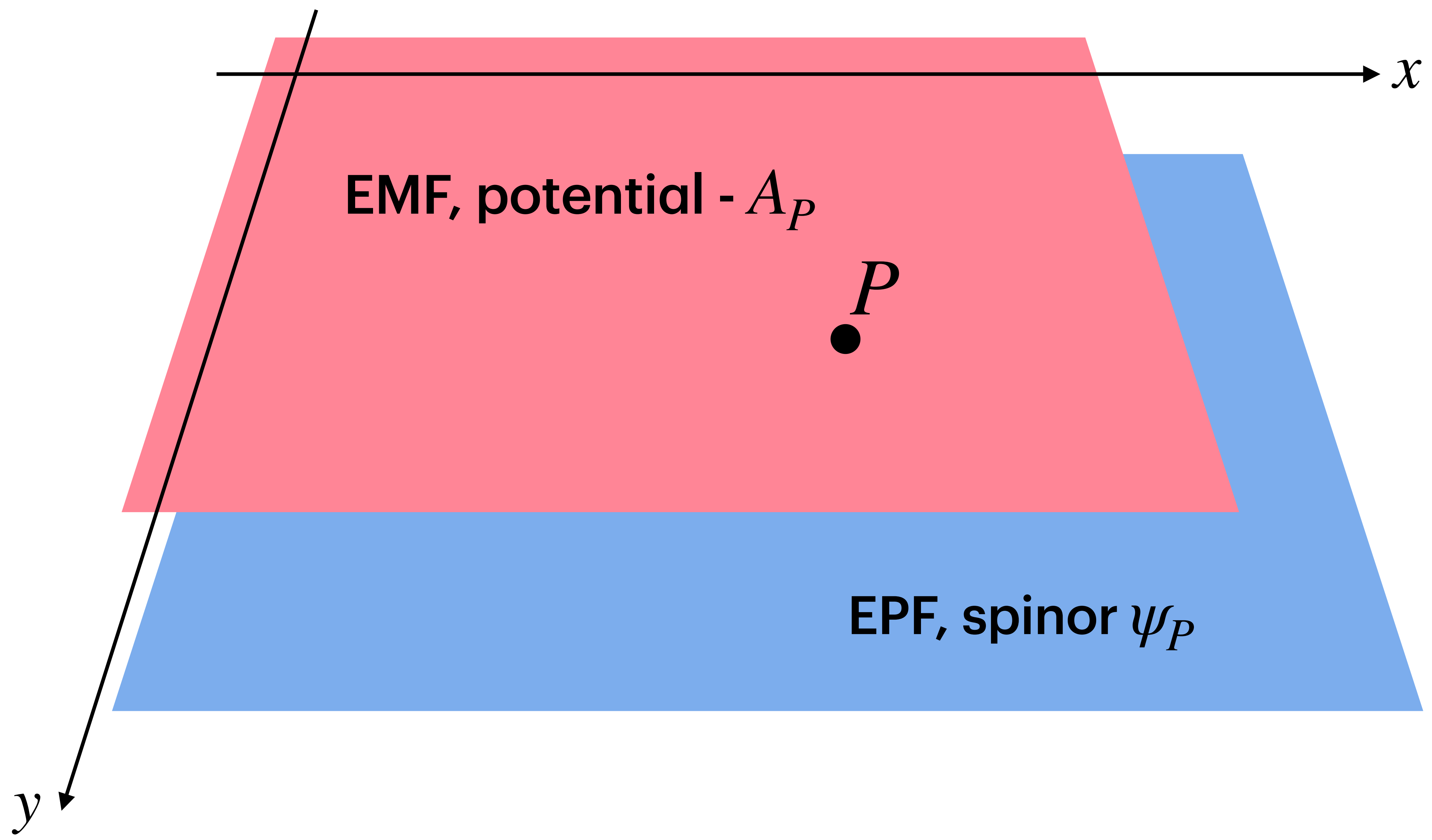
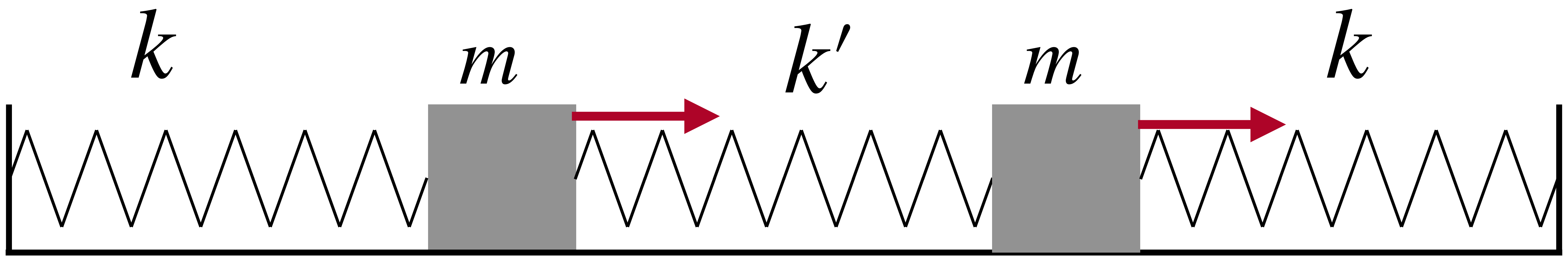



Everywhere.
Always.

# Modes

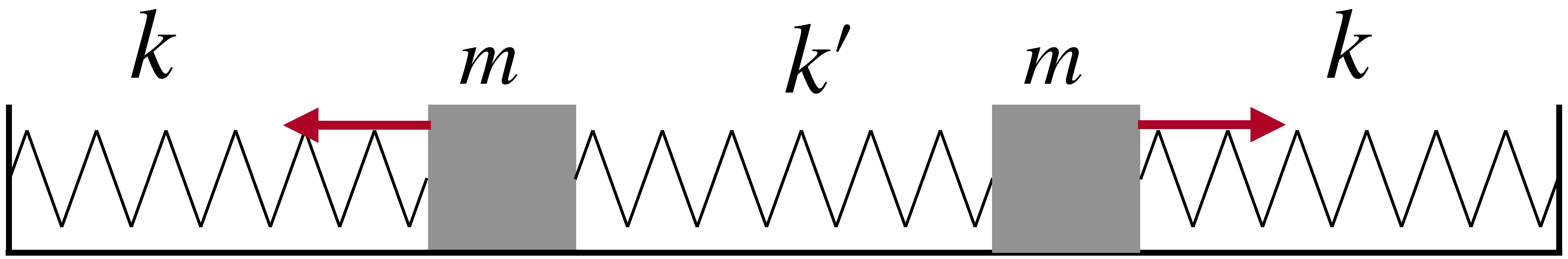
## A Very Important Concept

$$\omega_2 = \sqrt{k/m}$$




Mode 1

$$\omega_1 = \sqrt{(k+2k')/m}$$



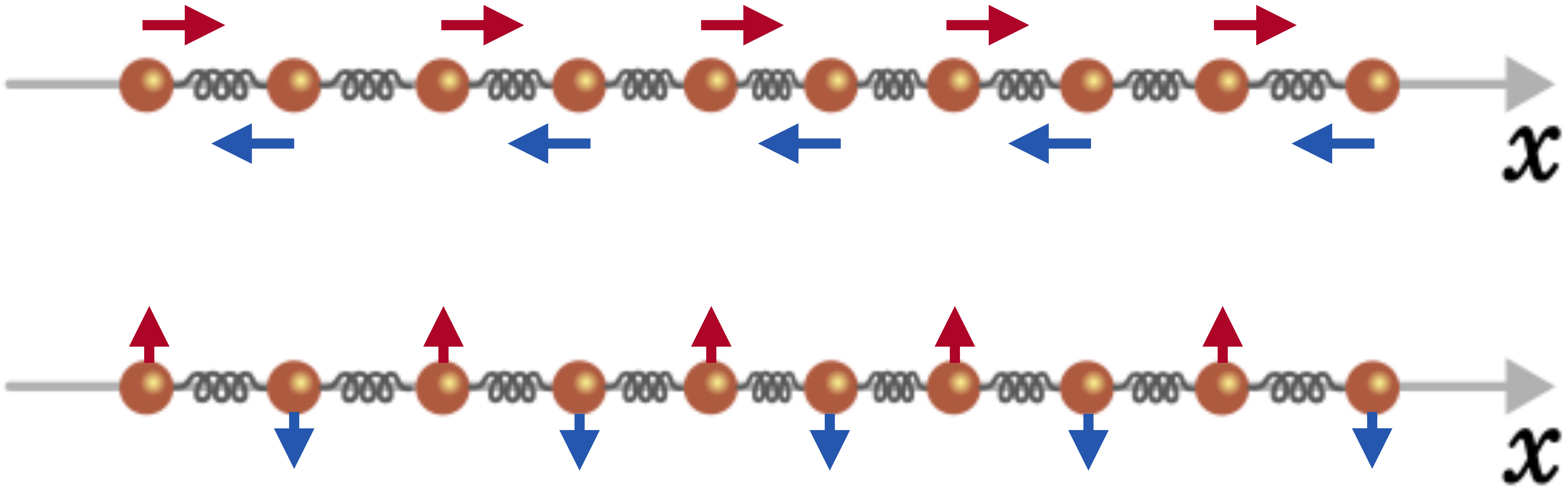

Mode 2

We learned about modes for a simple system.

# Modes

## A Very Important Concept

Number of modes grows.




Possible motions.

These are mechanical examples.

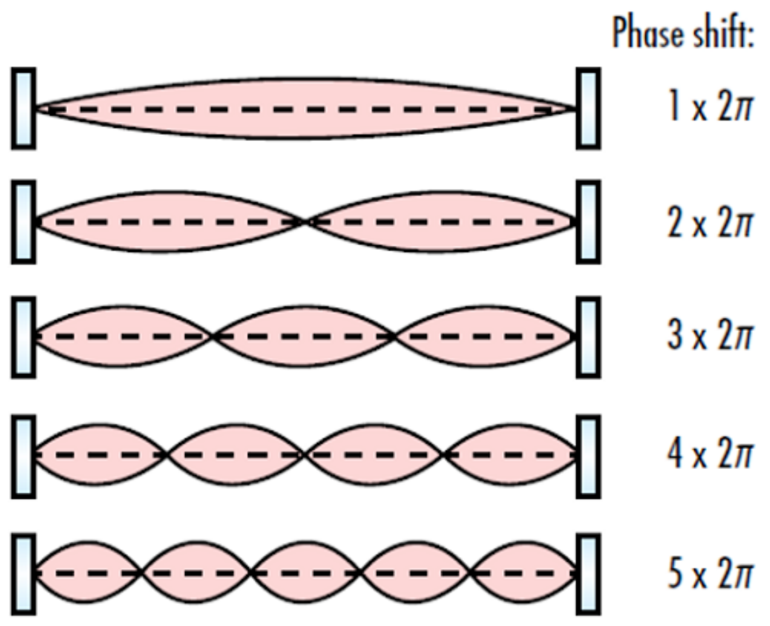
We learned about modes for a simple system. In homework assignment you will learn about more complicated systems.

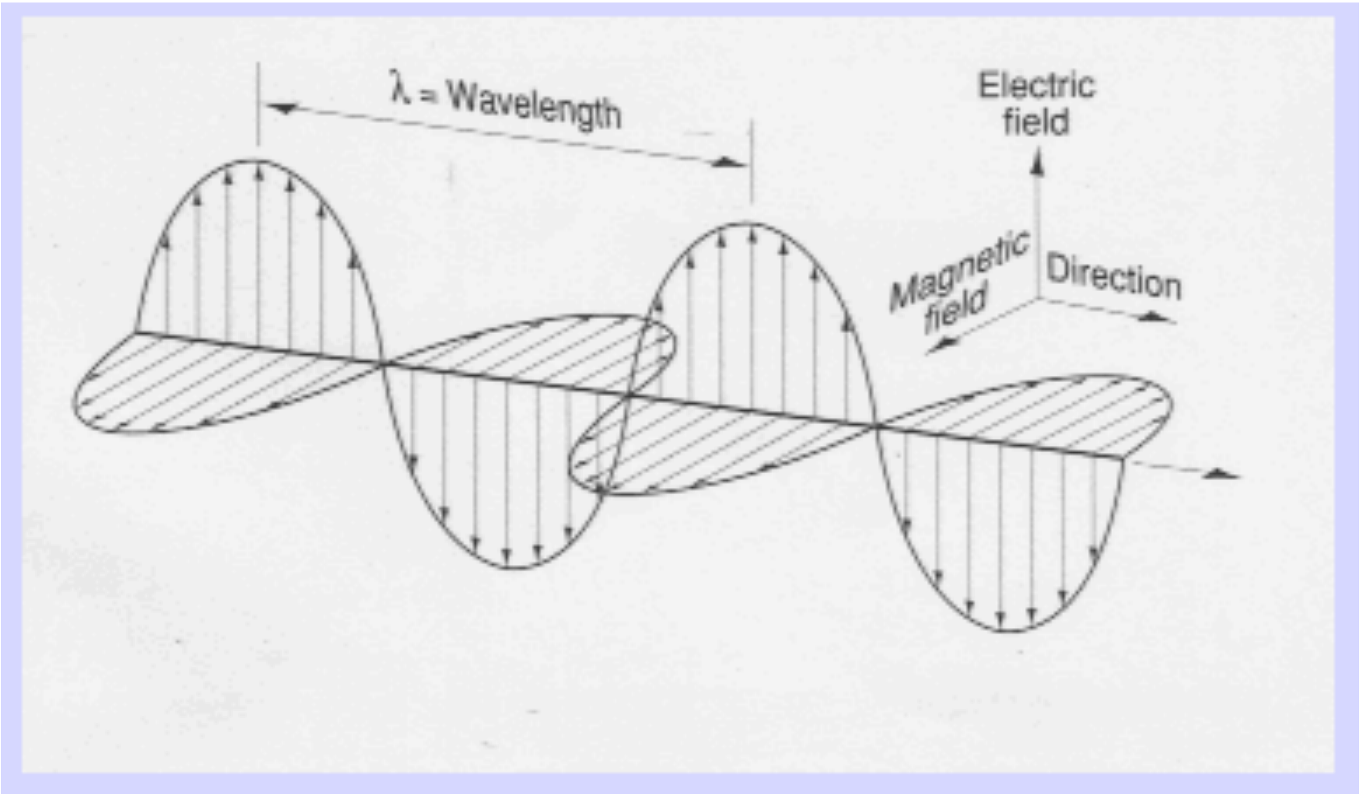
# Modes

## Of Electromagnetic Fields

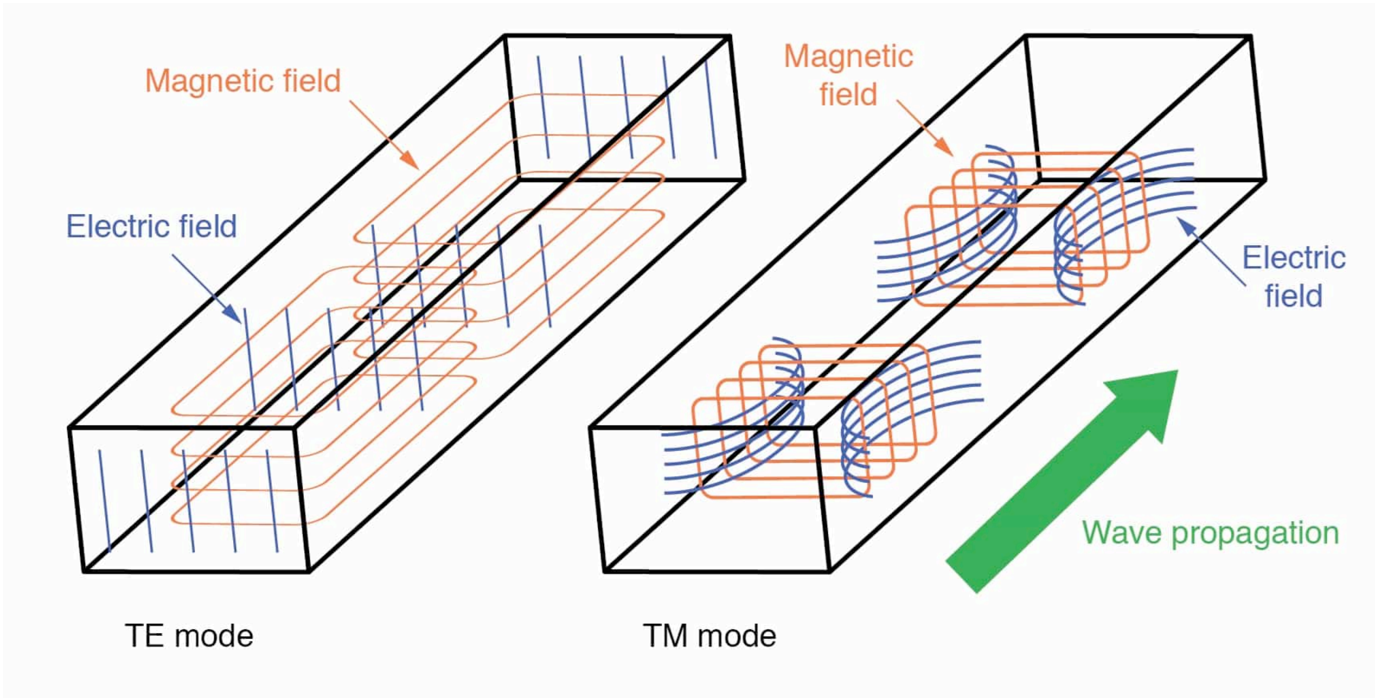
Waves

Trapped




Traveling




Cavities

Waveguides

# Modes

## Of Electromagnetic Fields

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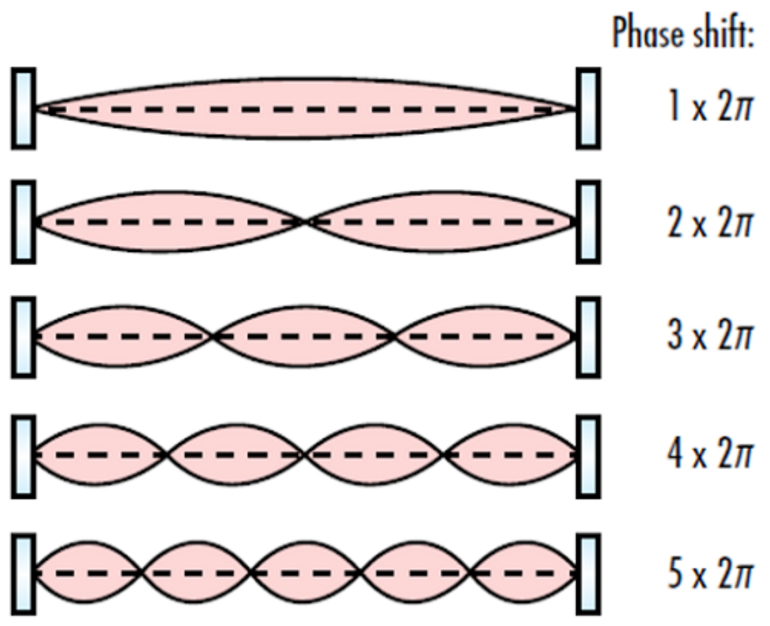


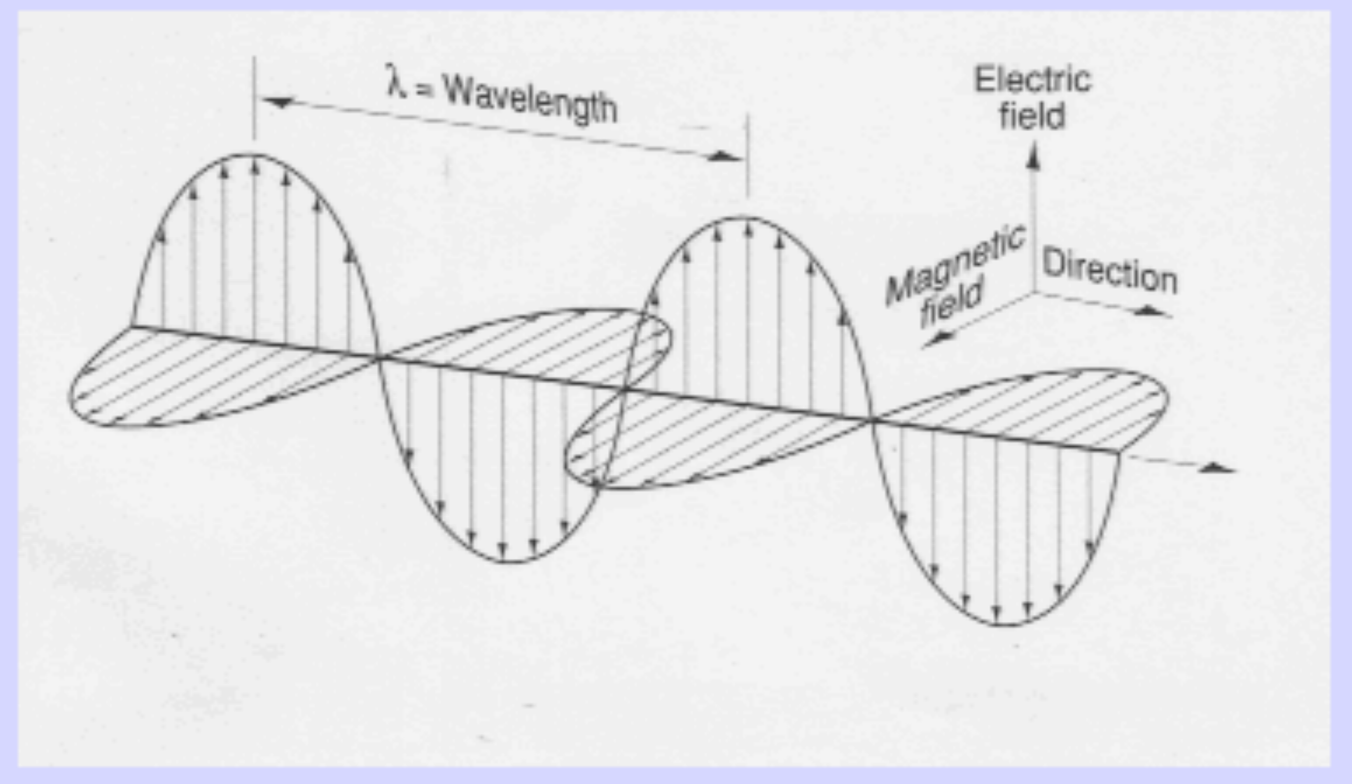


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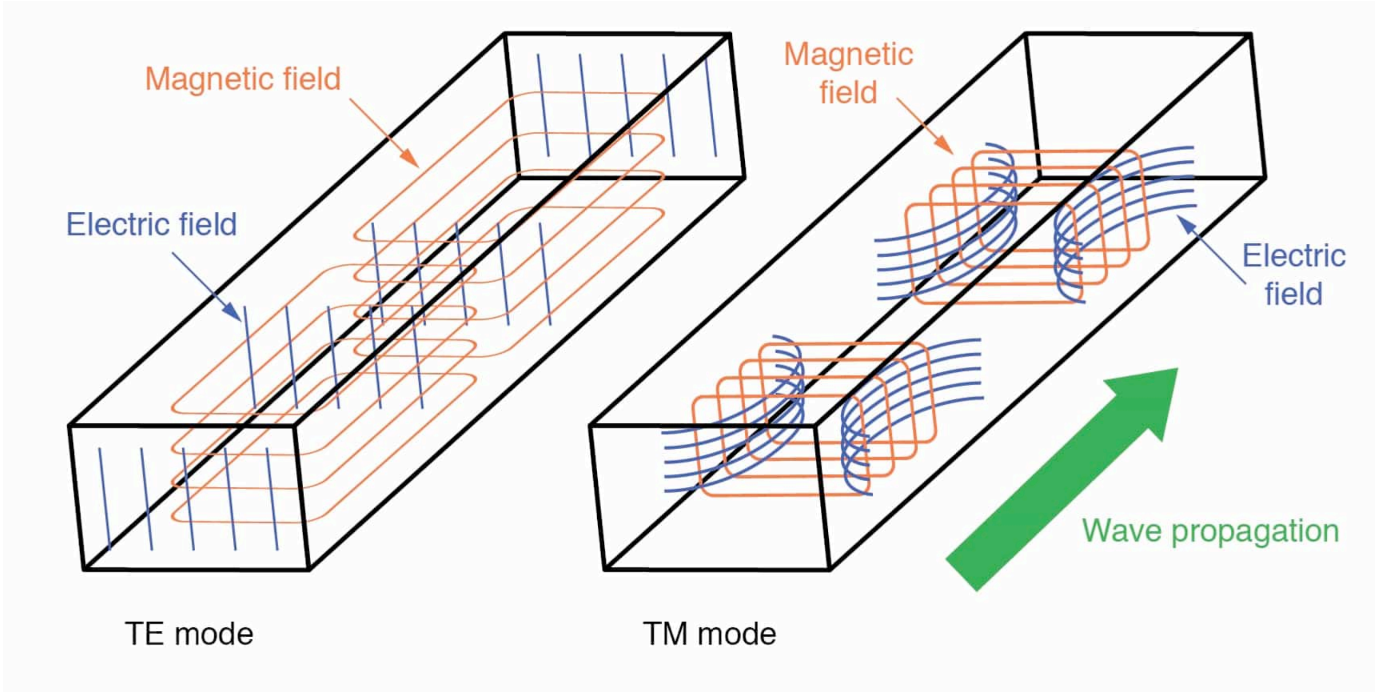


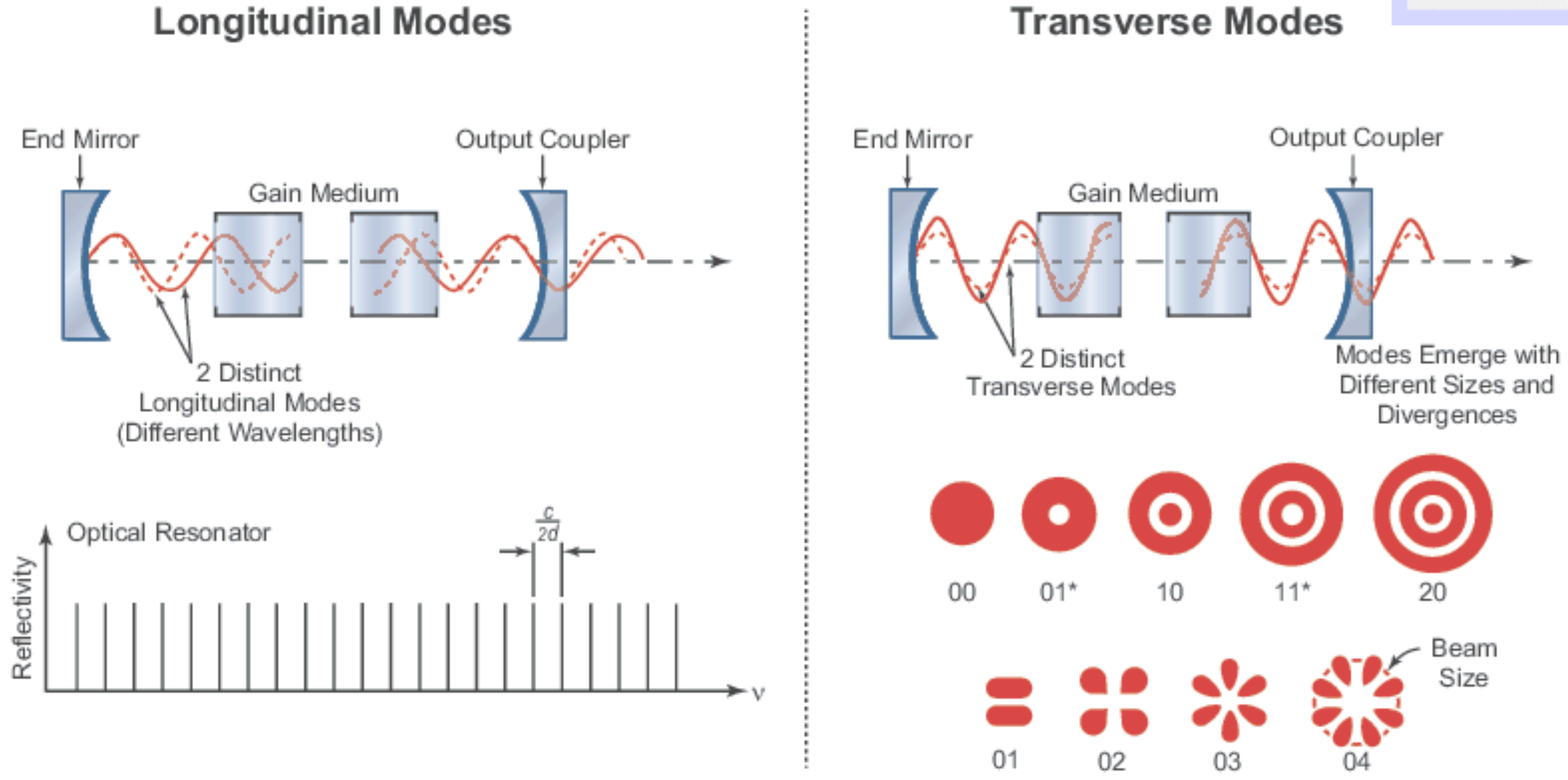


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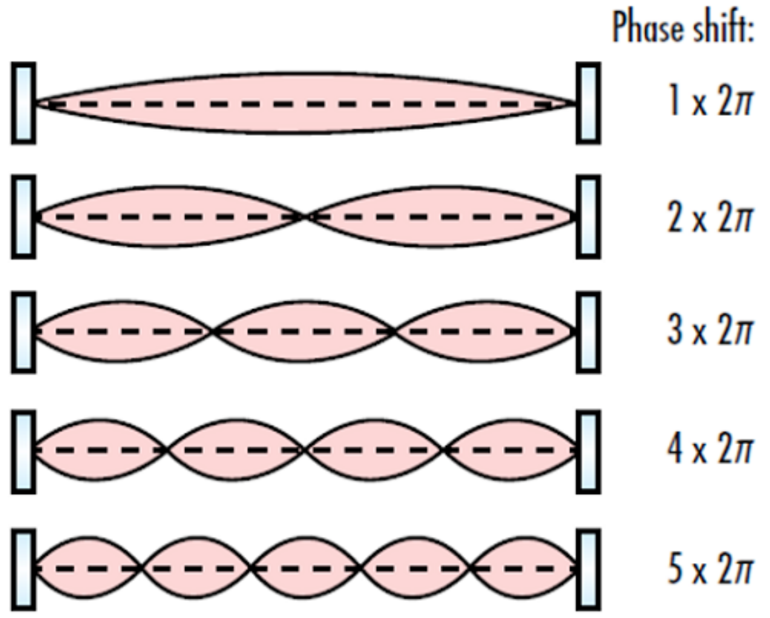


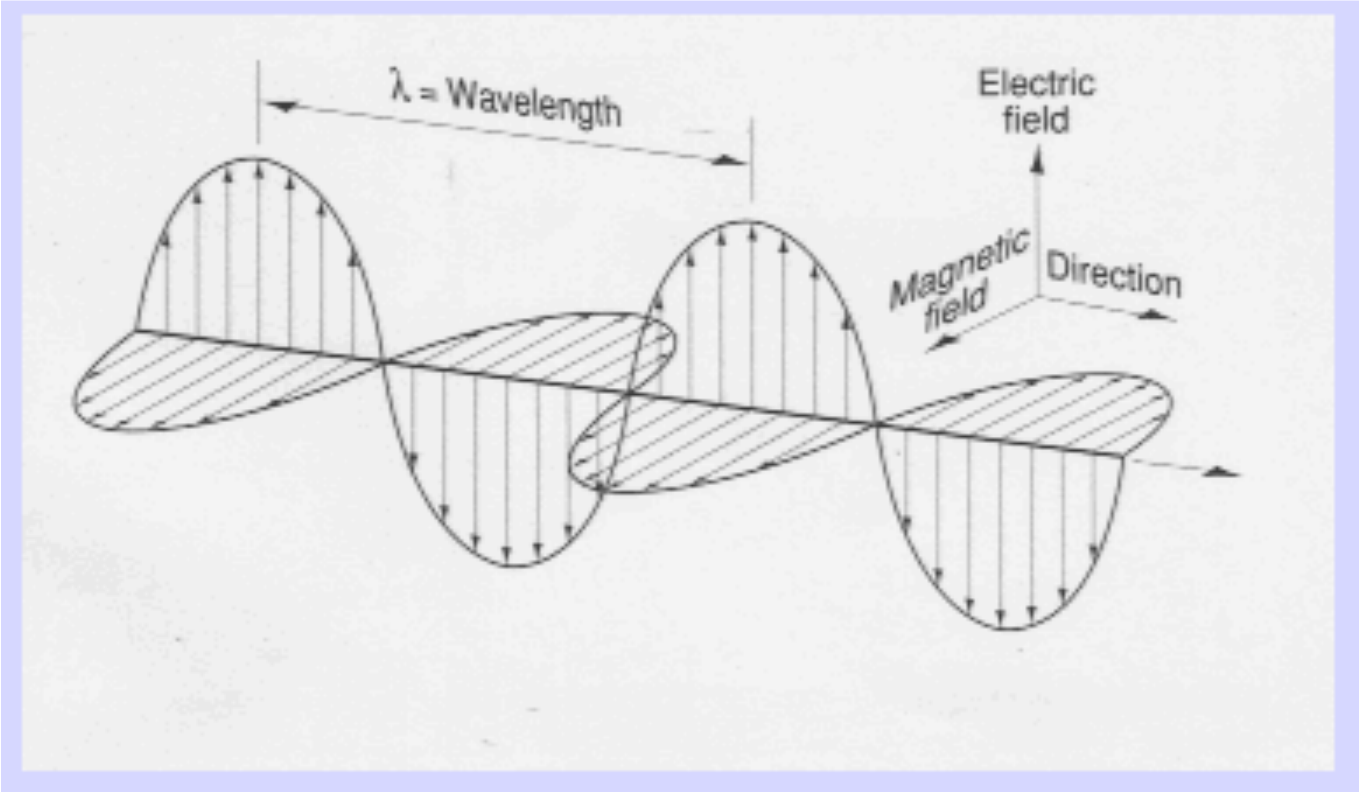


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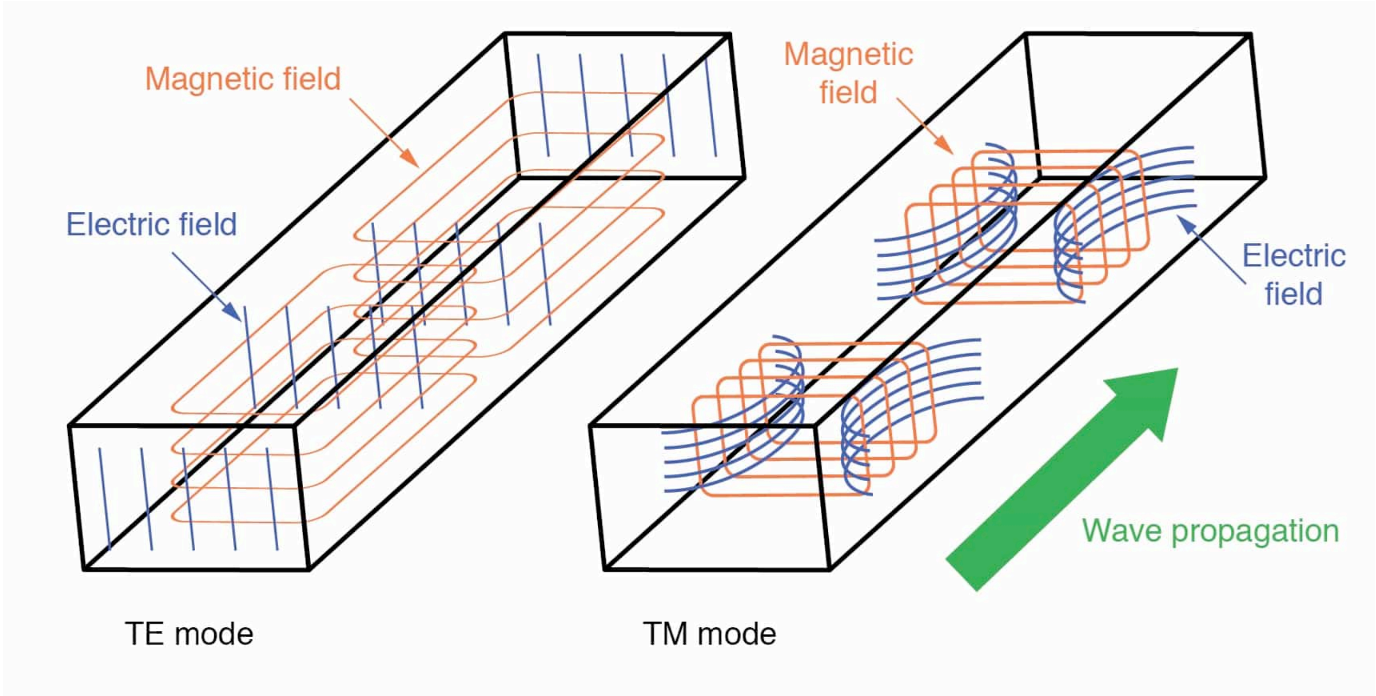
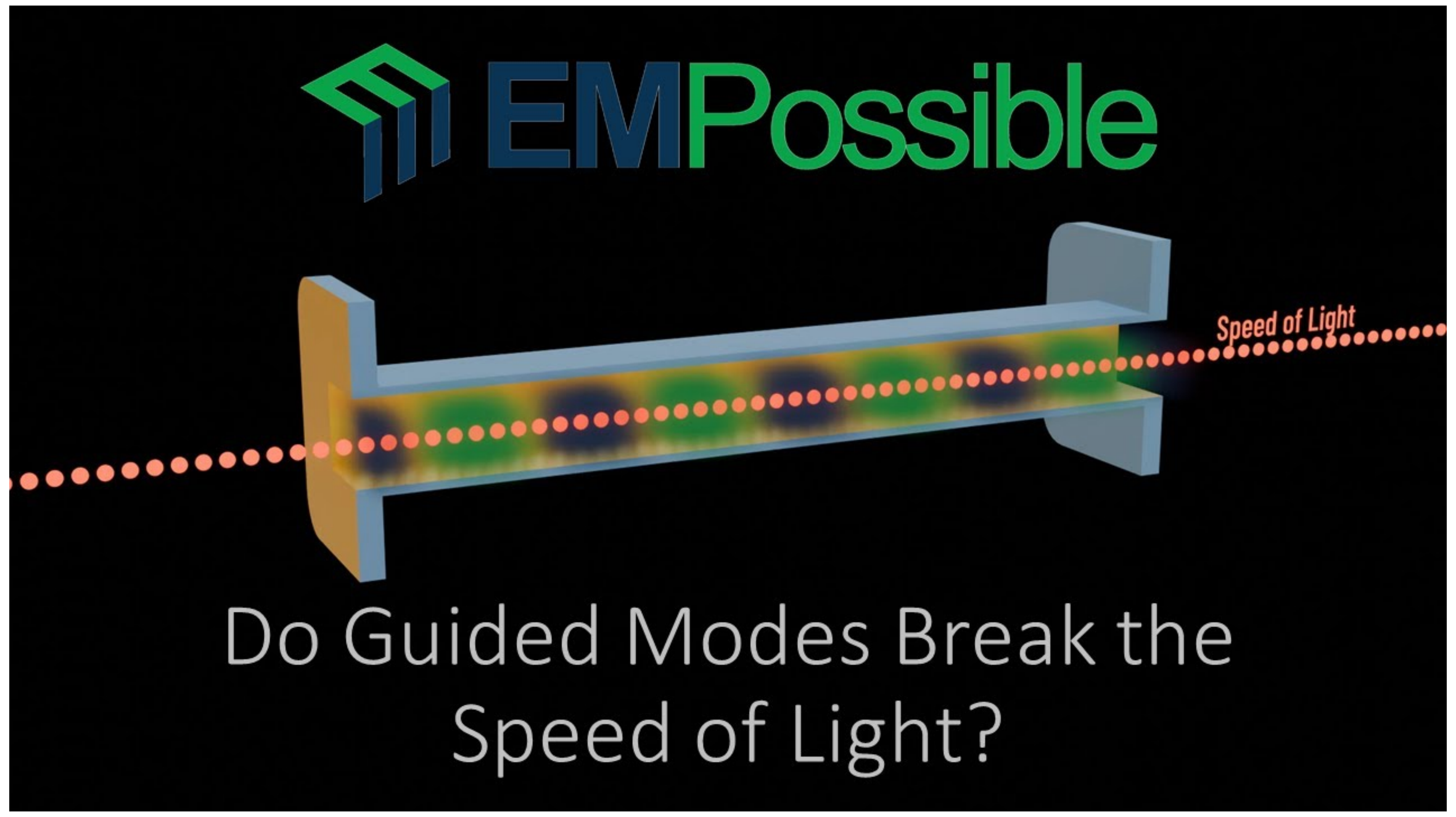


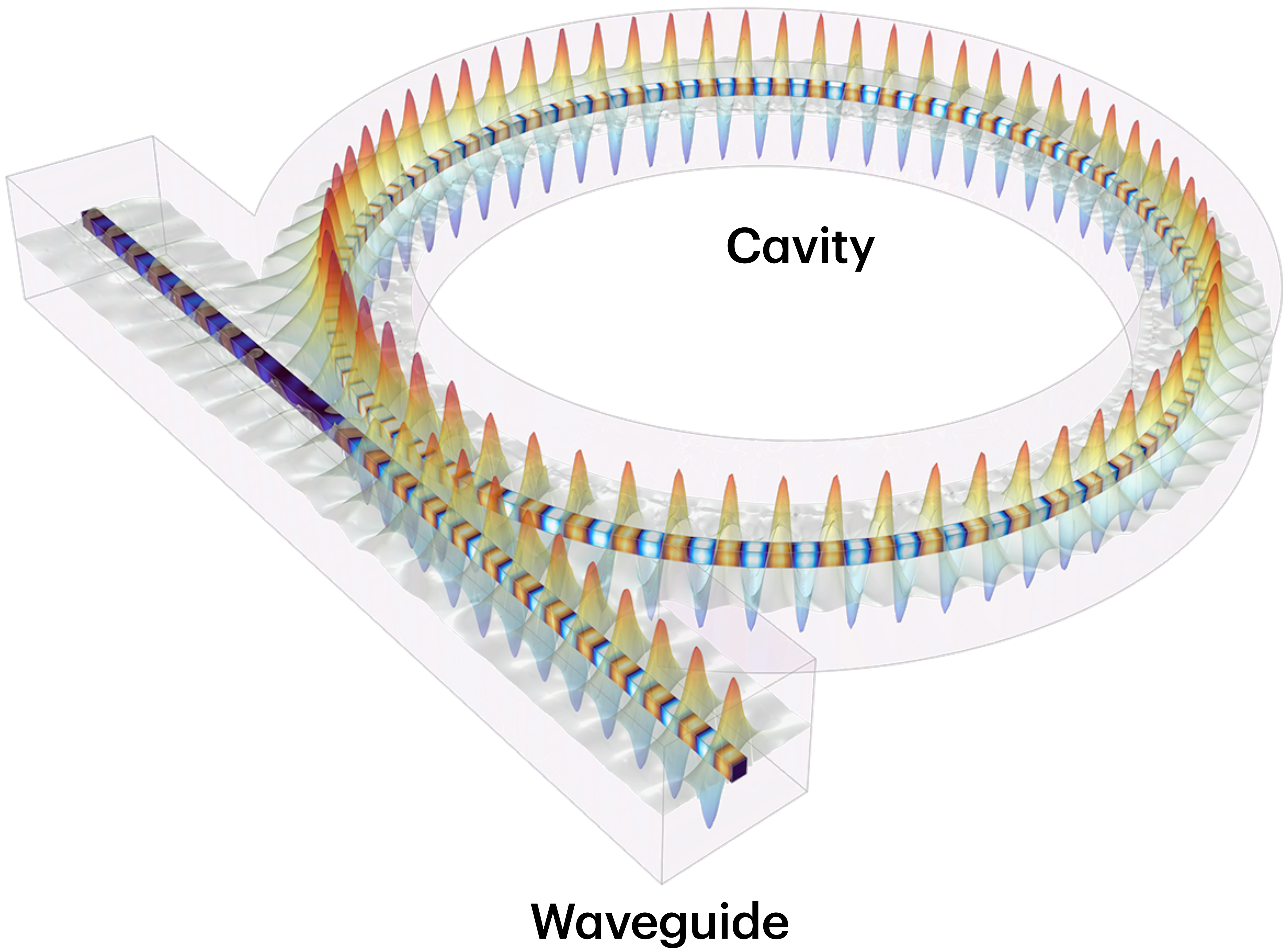

Superb Youtube Channel for EnM

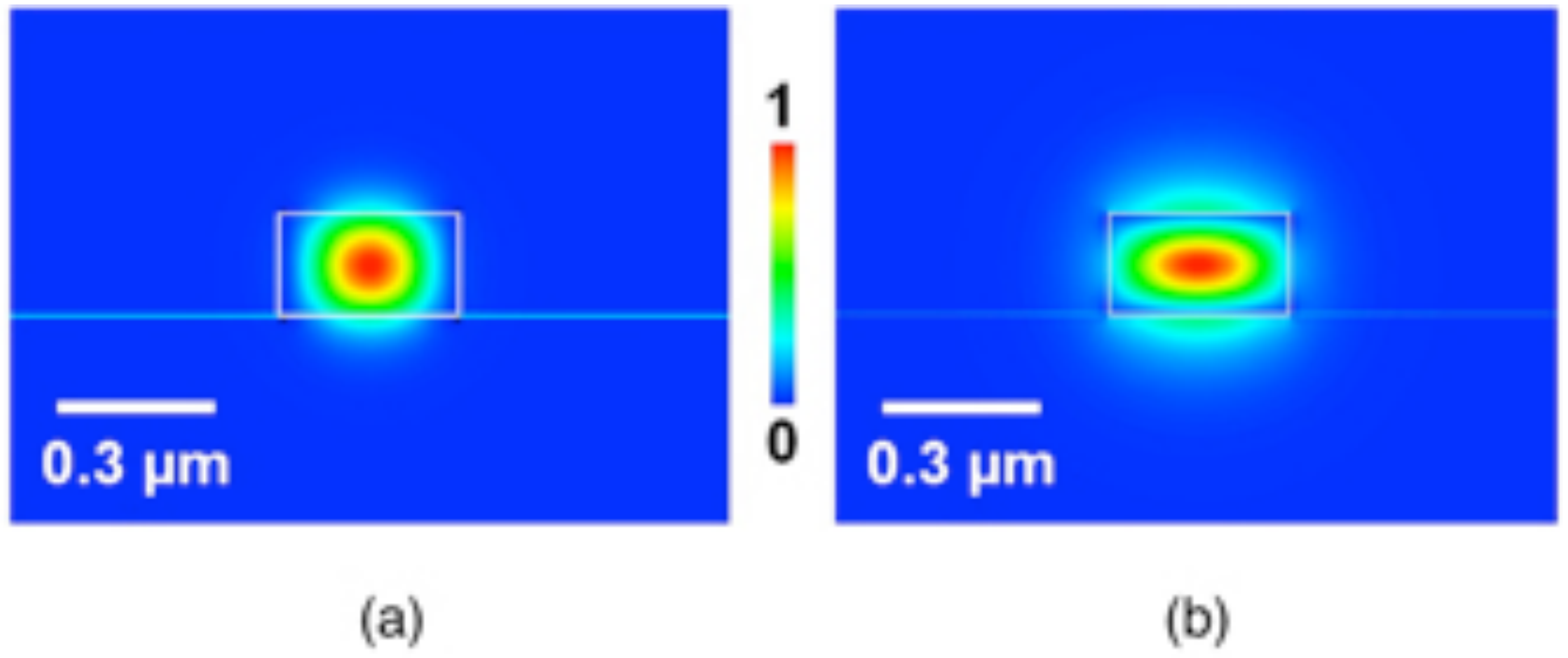
Cavities

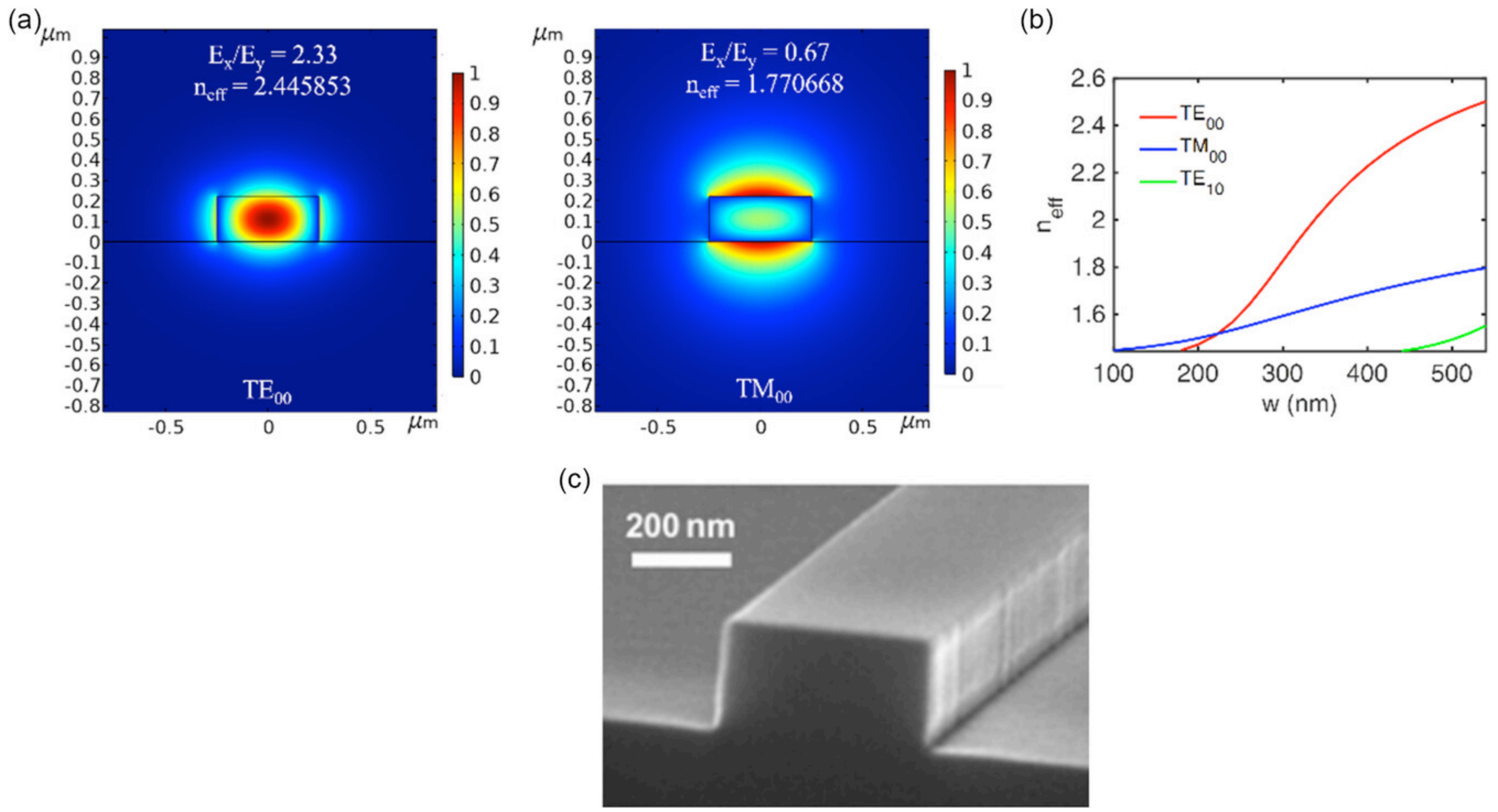
Waveguides

# Modes

## Of Electromagnetic Fields

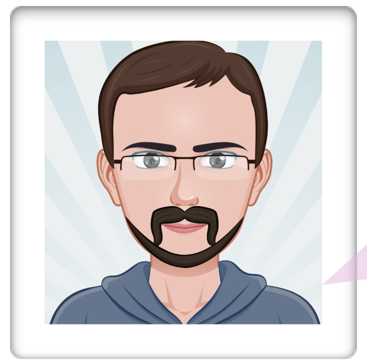


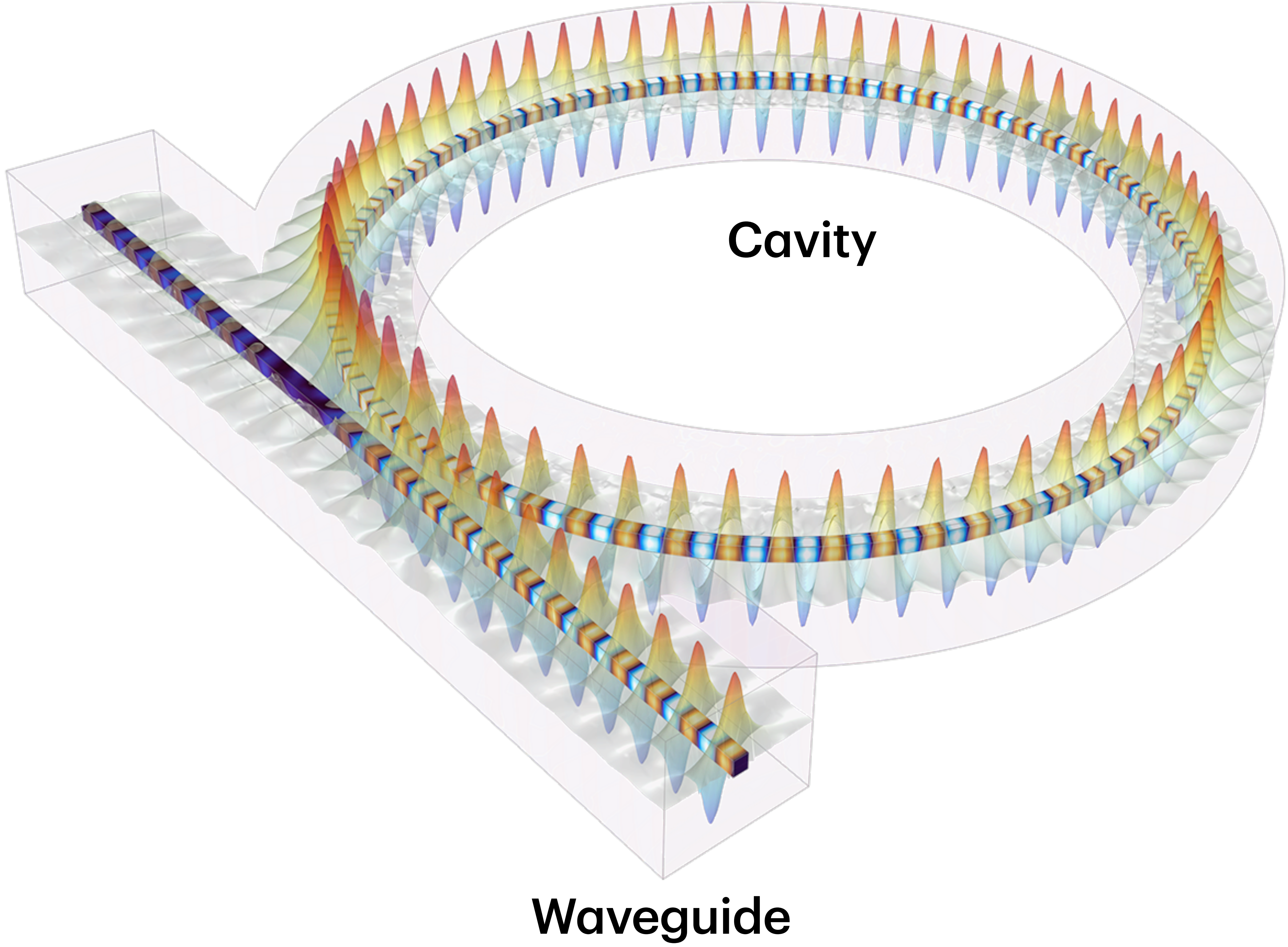



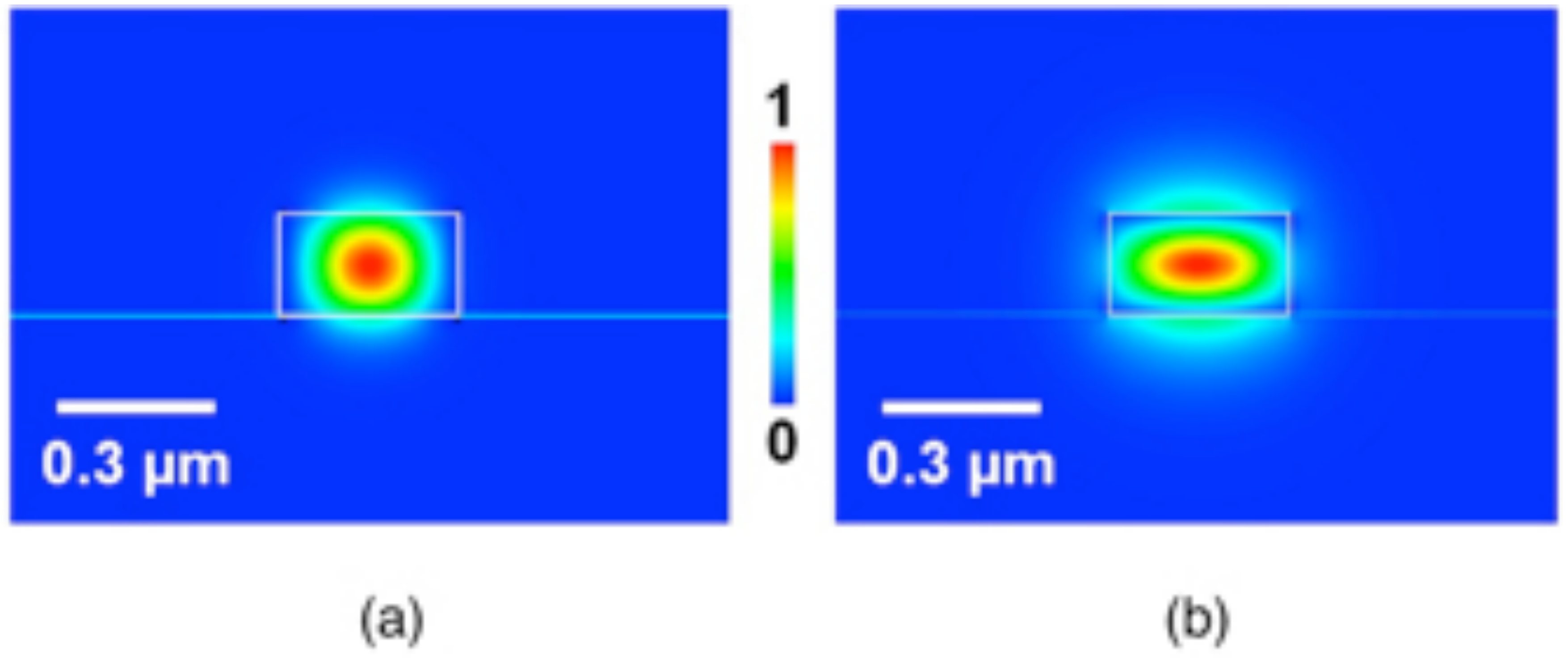
# Modes

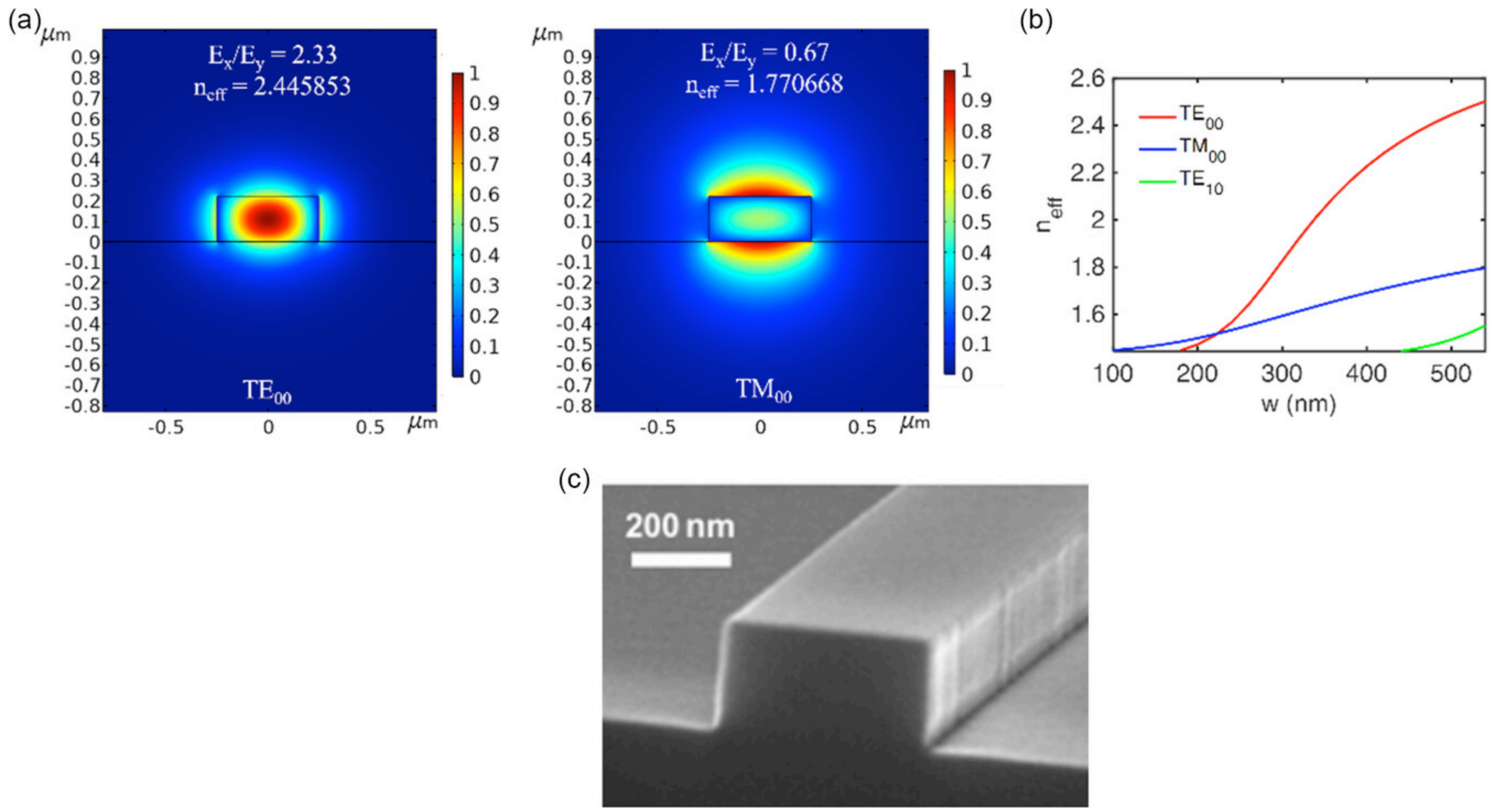
## Of Electromagnetic Fields



Recall hydrogen atom and an electron as a standing wave.

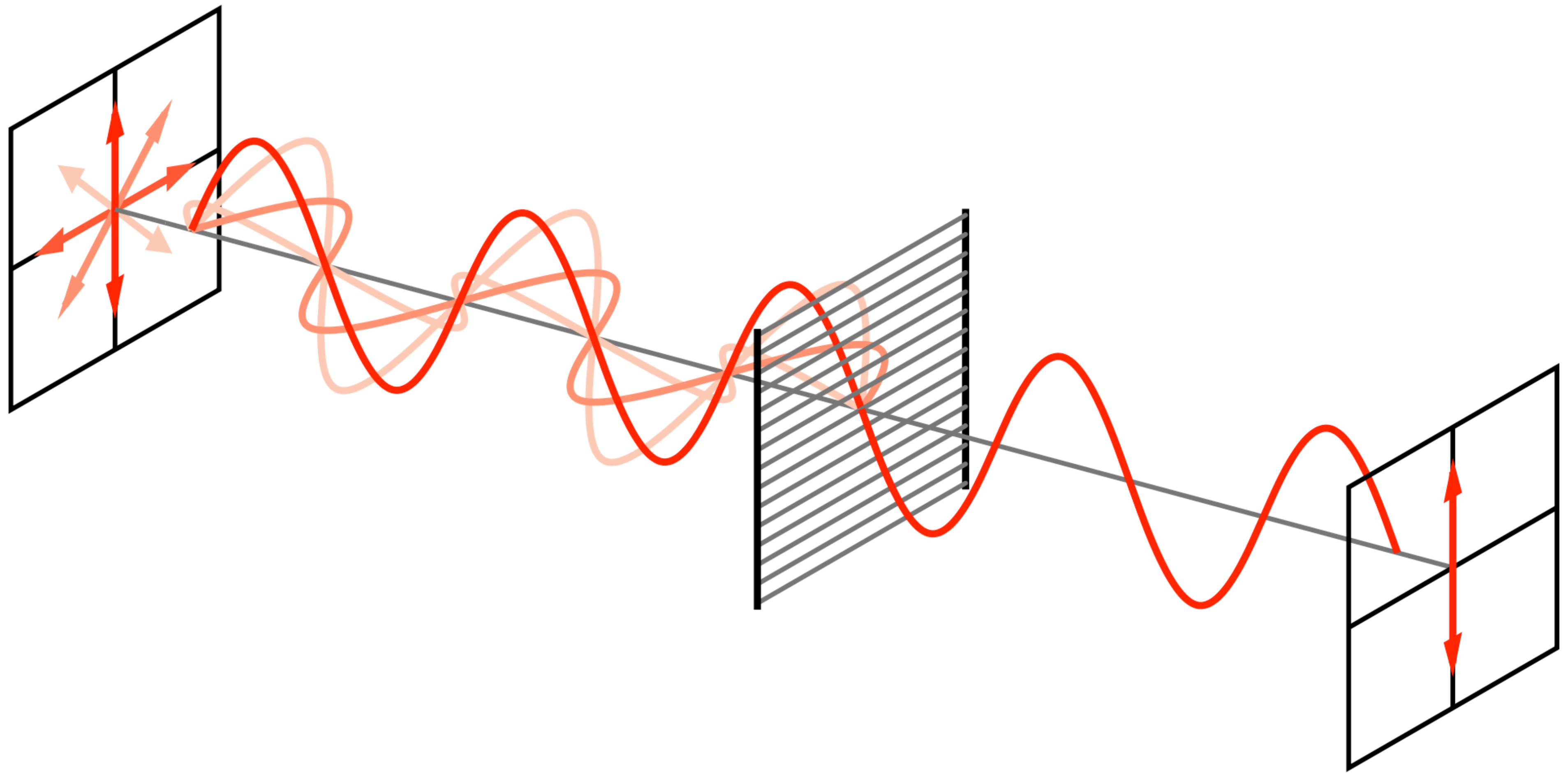


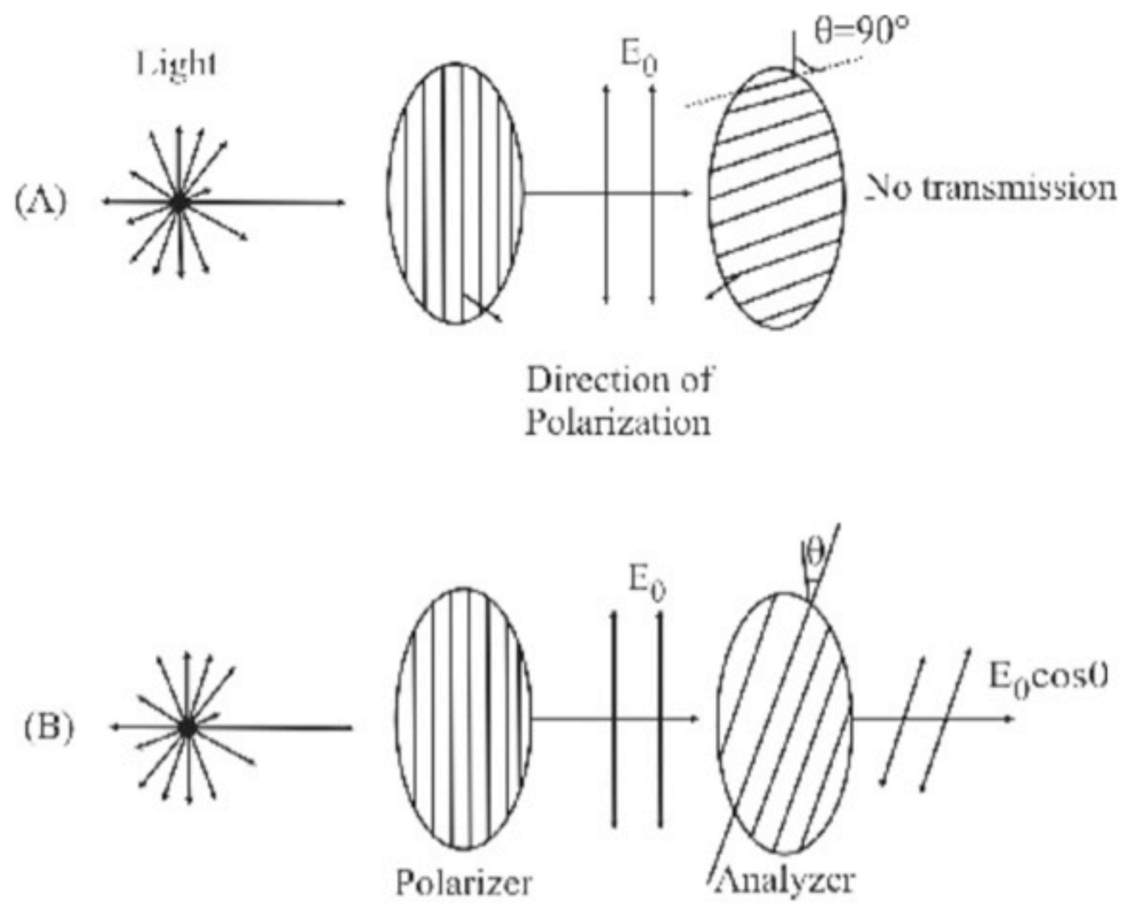



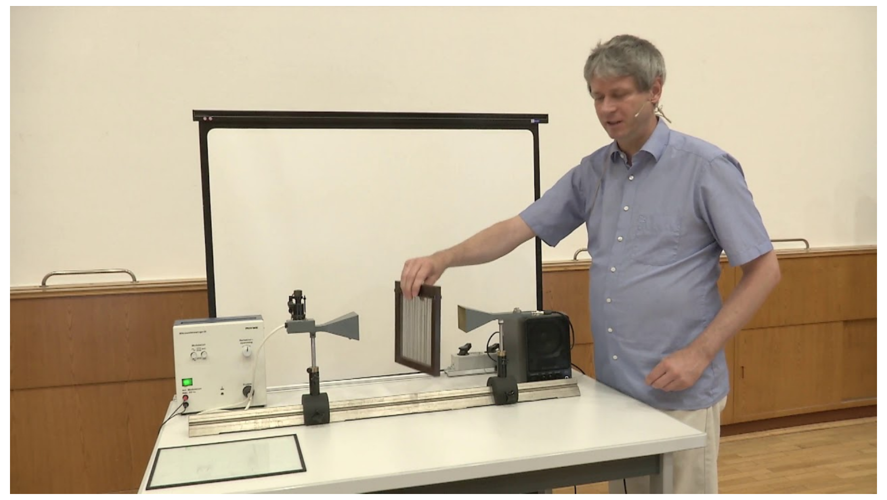
# Polarization

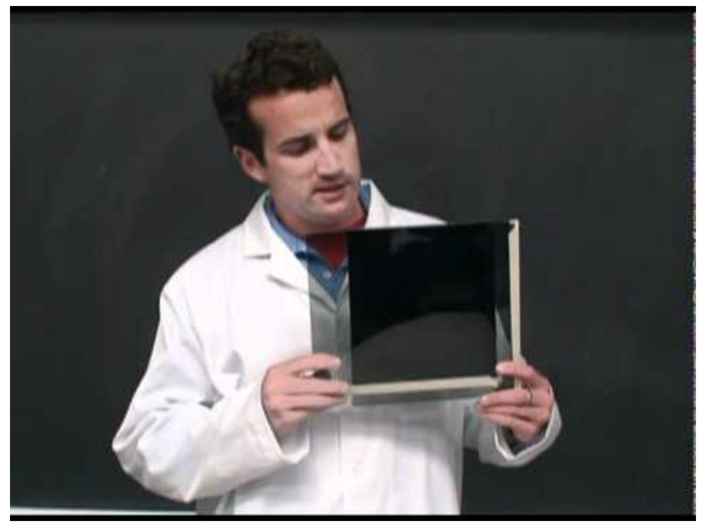
## Of Electromagnetic Field



### Malus Law



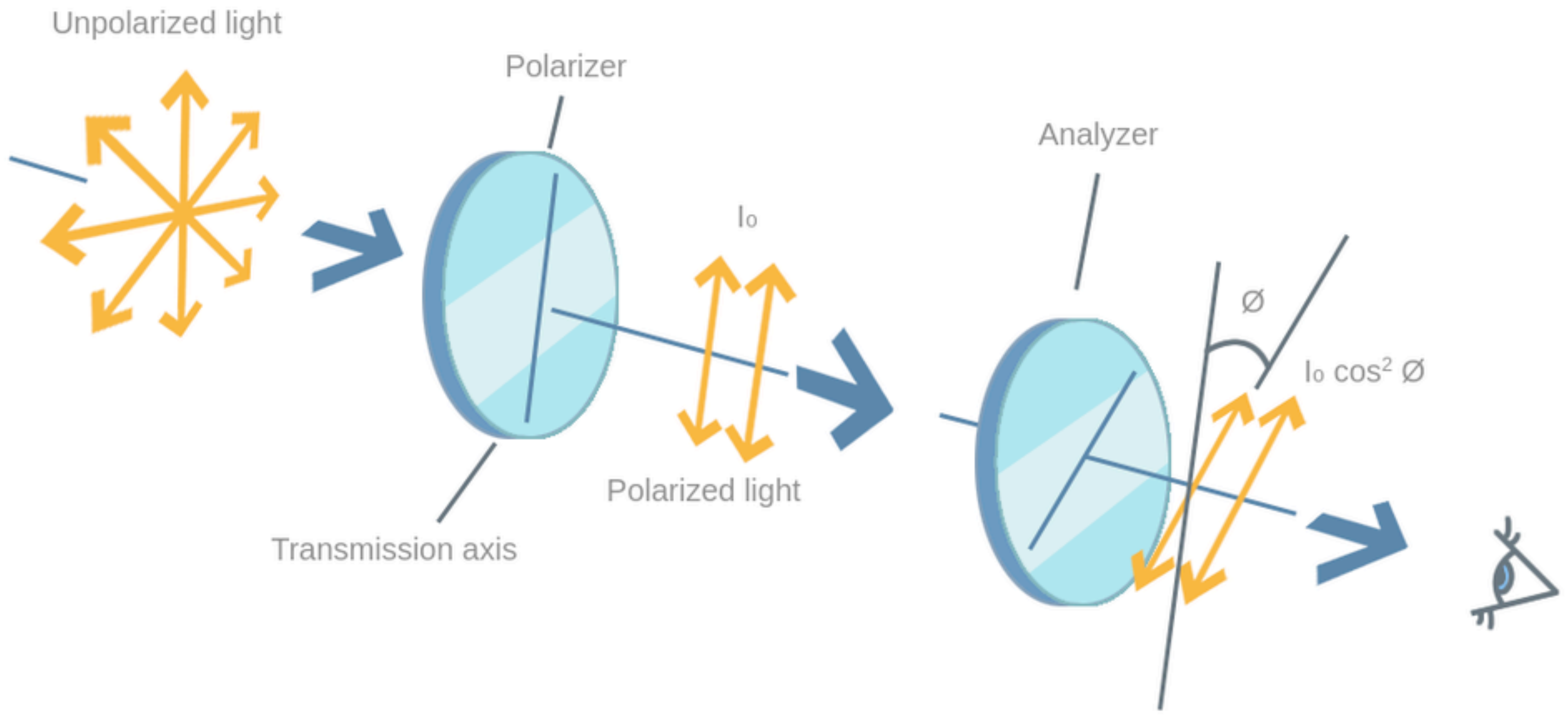





# Polarization

## Of Photons

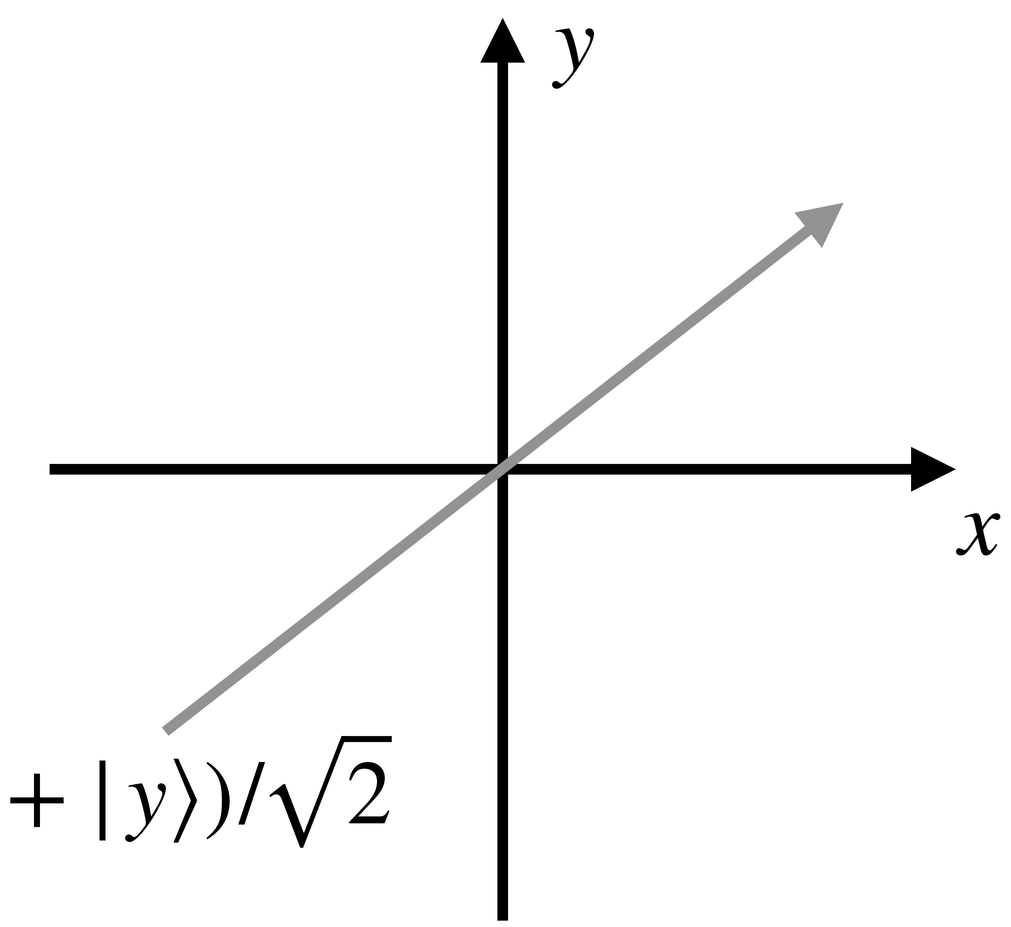
### The Law of Malus




$$I = \Delta E/\Delta t = h\nu\Delta N/\Delta t = h\nu R$$

What changes with angle — number of photons per second that goes through.

$|\Psi_H\rangle = |x\rangle$ $\qquad$ $|\Psi_V\rangle = |y\rangle$



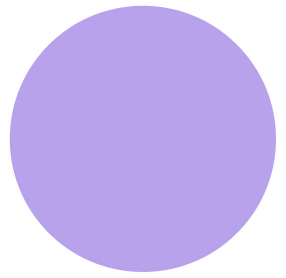

$|\Psi\rangle = (|x\rangle + |y\rangle)/\sqrt{2}$

$$|\Psi\rangle = a|x\rangle + b|y\rangle$$

# Spin

## As Intrinsic (Internal) Angular Momentum

$$s = 0, \boxed{\frac{1}{2}}, 1, \frac{3}{2}, \dots, \frac{n}{2}$$



“Bad model” for particles (electrons, photons, and other *-ons)

- Mass — number
- Charge — number
- Spin — vector, spinor, tensor/operator

- Spin is revealed indirectly.
  - Via magnetic moment
  - Via “statistics” — group behavior of a large number of particles.

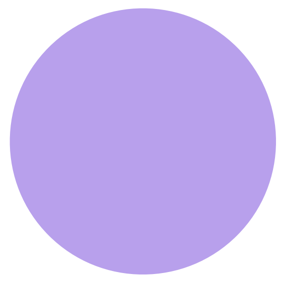
Spin has nothing to do with “spinning”.
Bad word stuck.

# Spin

## As Intrinsic (Internal) Angular Momentum

**Electrons, positrons**

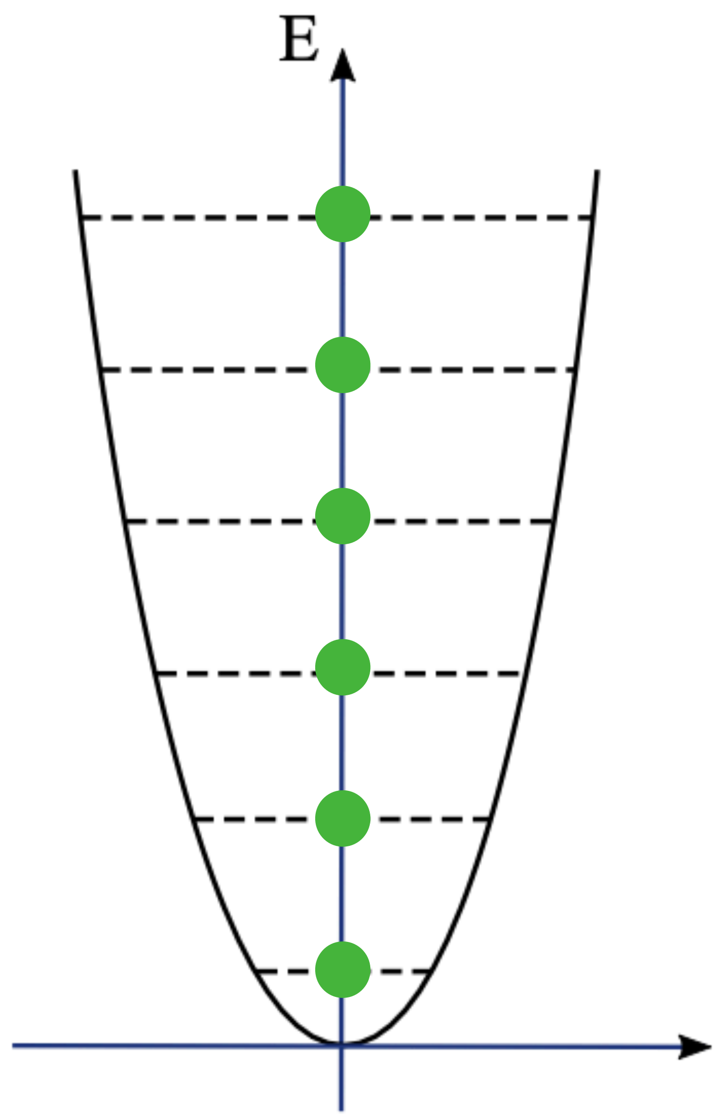
$$s = 0, \boxed{\frac{1}{2}}, 1, \frac{3}{2}, \ldots, \frac{n}{2}$$



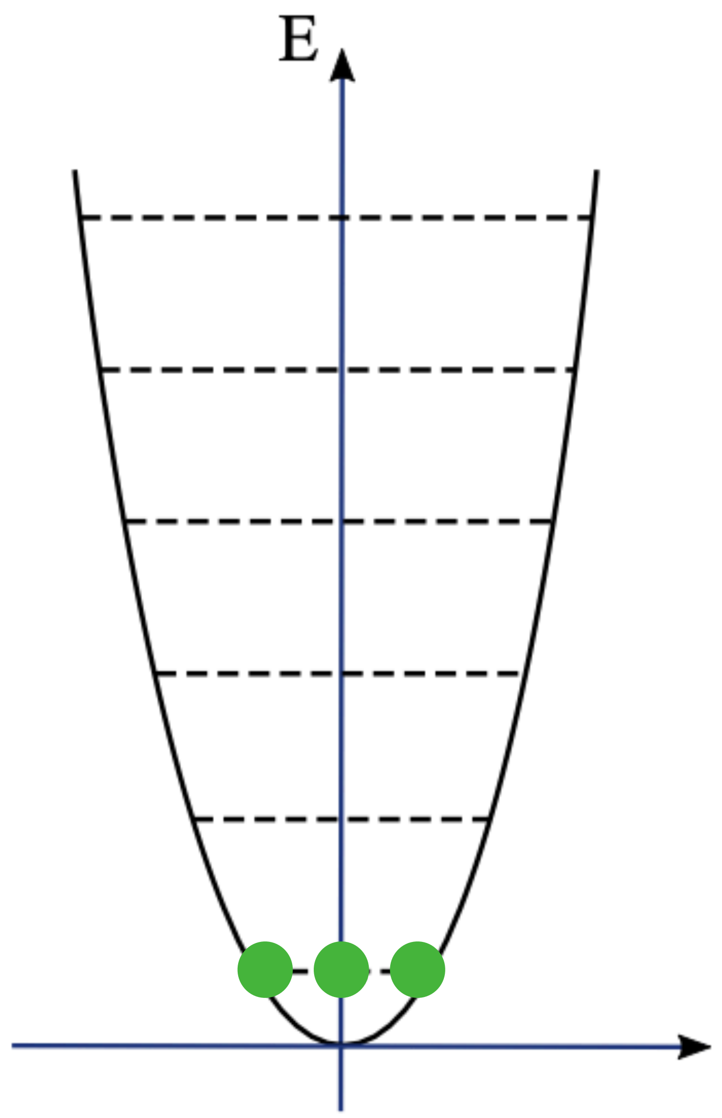
**“Bad model” for particles (electrons, photons, and other *-ons)**

- **Mass — number**
- **Charge — number**
- **Spin — vector, spinor, tensor/operator**

- Spin is revealed indirectly.
  - Via magnetic moment $\quad \vec{m} \propto \frac{q}{2m}\vec{S}$
  - Via “statistics” — group behavior of a large number of particles.




**Fermions,** $s = (2n+1)/2$




**Bosons,** $s = n$

# Spin And Polarization

## As Degrees Of Freedom

- Polarization is a necessary information about EMF.
- Polarization can be manipulated and used.
- Polarization is a resource — degree of freedom.

$$\boxed{|\Psi\rangle = |\Phi_x\rangle |Polarization\rangle}$$

- Spin is a necessary information about EPF.
- Spin *orientation* can be manipulated and used.
- Spring is a resource — degree of freedom.

$$\boxed{|\Psi\rangle = |\Phi_x\rangle |Spin\rangle}$$

# Spin And Polarization

## As Degrees Of Freedom

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$$\boxed{|\Psi\rangle = |\Phi_x\rangle|Polarization\rangle}$$

Distribution of field in space.

$$\boxed{|\Psi\rangle = |\Phi_x\rangle|Spin\rangle}$$

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# Spin And Polarization

## As Degrees Of Freedom

- Polarization is a necessary information about EMF.
- Polarization can be manipulated and used.
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$$|\Psi\rangle = |V\rangle \qquad |\Psi\rangle = |H\rangle$$

Example of polarization and spin states.

$$|\Psi\rangle = |\uparrow\rangle \qquad |\Psi\rangle = |\downarrow\rangle$$

- Spin is a necessary information about EPF.
- Spin *orientation* can be manipulated and used.
- Spring is a resource — degree of freedom.

# Self-Test

## Answer These Questions 1hr After Class

1. How is mode different from motion of individual body?
2. What physical systems may have modes?
3. What are two types of “devices” used to contain modes? What is the difference between them.
4. What is polarization?
5. What is Malus law?
6. What is spin?
7. What are two basic types of particles?

# Homework Problems

## Oscillators

1. Play with the simulations:
    1. https://www.falstad.com/coupled/
    2. https://phet.colorado.edu/sims/html/normal-modes/latest/normal-modes_all.html
    3. https://quantumatlas.umd.edu/entry/measuring-polarization/
2. Watch the videos:
    1. https://youtu.be/OLNFrxgMJ6E
    2. https://youtu.be/KG3NpfpXfXM
    3. https://youtu.be/E9qpbt0v5Hw
    4. https://youtu.be/WJ9uuA17sB0

# Quantum Theory

## In a Nutshell

### II. POSTULATES FOR QUANTUM MECHANICS

In this paper, all state vectors are supposed to be normalized, and mixed states are represented by density operators, i.e., positive operators with unit trace. Let $A$ be an observable with a nondegenerate purely discrete spectrum. Let $\phi_1, \phi_2, \ldots$ be a complete orthonormal sequence of eigenvectors of $A$ and $a_1, a_2, \ldots$ the corresponding eigenvalues; by assumption, all different from each other.

According to the standard formulation of quantum mechanics, on the result of a measurement of the observable $A$ the following postulates are posed:

(A1) *If the system is in the state $\psi$ at the time of measurement, the eigenvalue $a_n$ is obtained as the outcome of measurement with the probability $|\langle\phi_n|\psi\rangle|^2$.*

(A2) *If the outcome of measurement is the eigenvalue $a_n$, the system is left in the corresponding eigenstate $\phi_n$ at the time just after measurement.*

The postulate (A1) is called the *statistical formula*, and (A2) the *measurement axiom*. The state change $\psi \mapsto \phi_n$ described by the measurement axiom is called the *state reduction*.

You will understand this paragraph in the end of the course.