

Title: Condensed Matter Review (PHYS 637) - Lecture 1

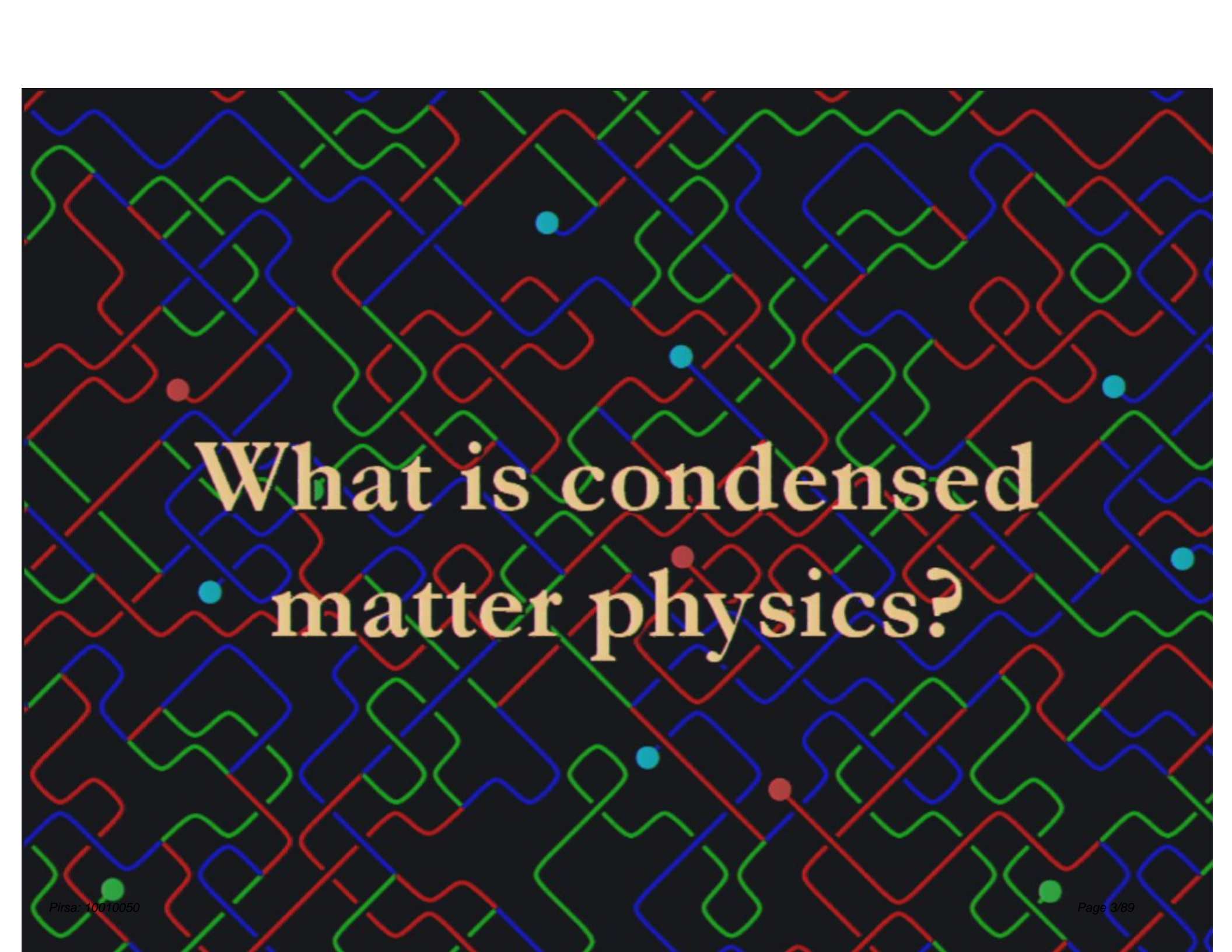
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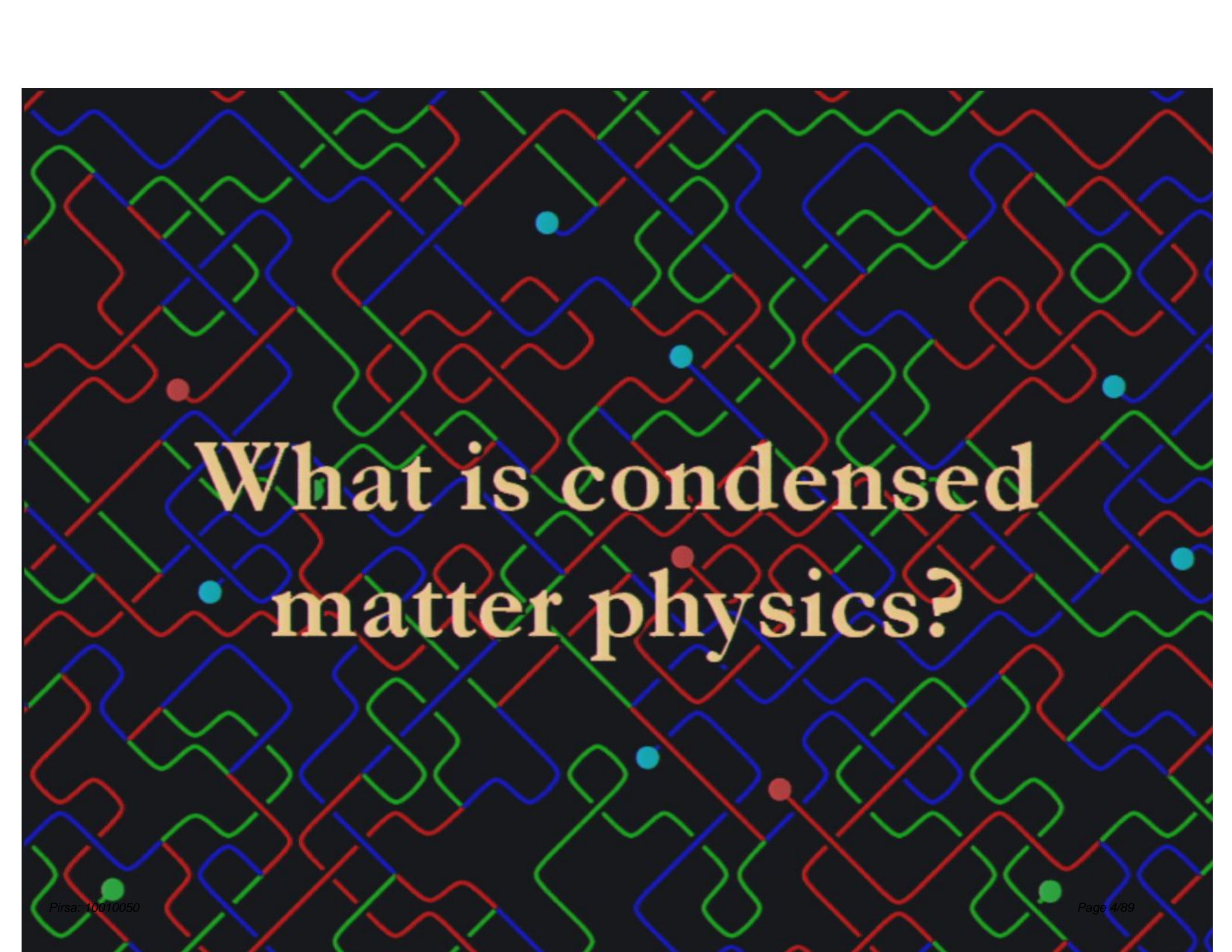
Abstract:



perimeter scholars
international



What is condensed matter physics?



What is condensed matter physics?

A story of light and ether

Xiao-Gang Wen

MIT

<http://dao.mit.edu/~wen>

Scientists are detectives

So let us be detectives in the next hour
We want unlock the secrete of light

Scientists are detectives

**So let us be detectives in the next hour
We want unlock the secrets of light**

All detective work starts with a question

What is light ?



What is light ?



Sun rises over Lake Superior snowband

Some thing from the sun

What is this thing?

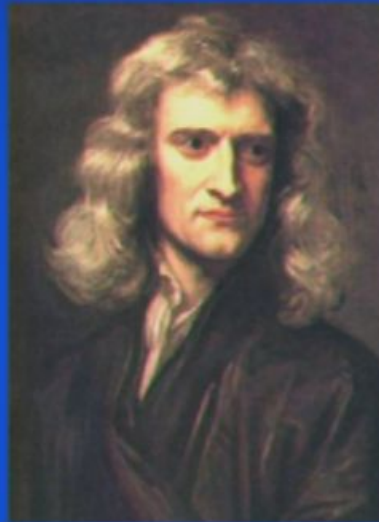


What is this thing?

Pierre Gassendi

Isaac Newton

- A ray of light =
A beam of particles

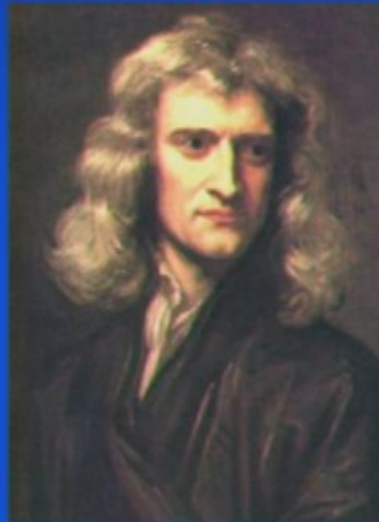


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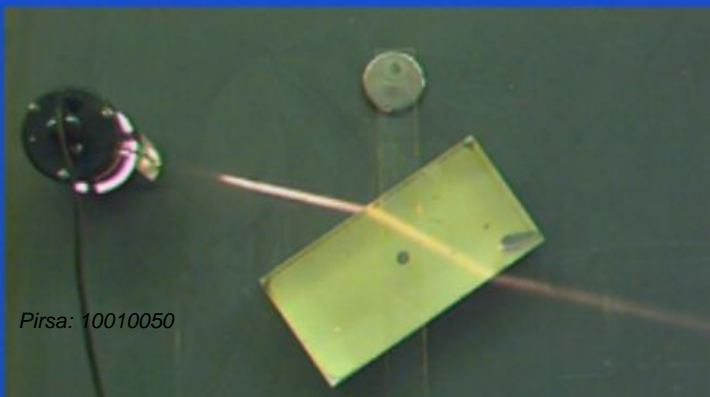
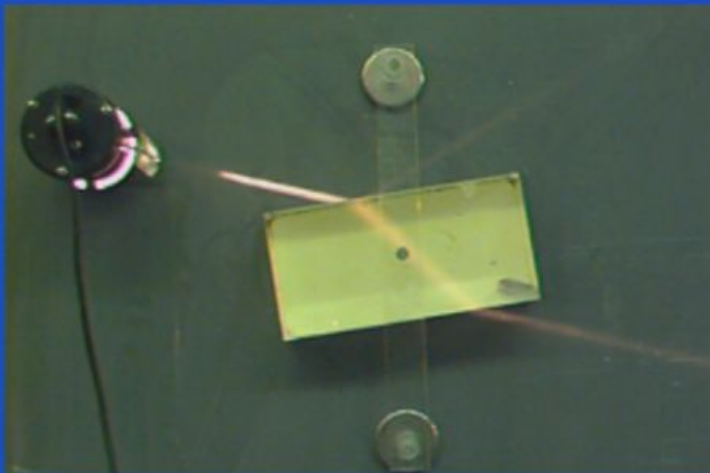
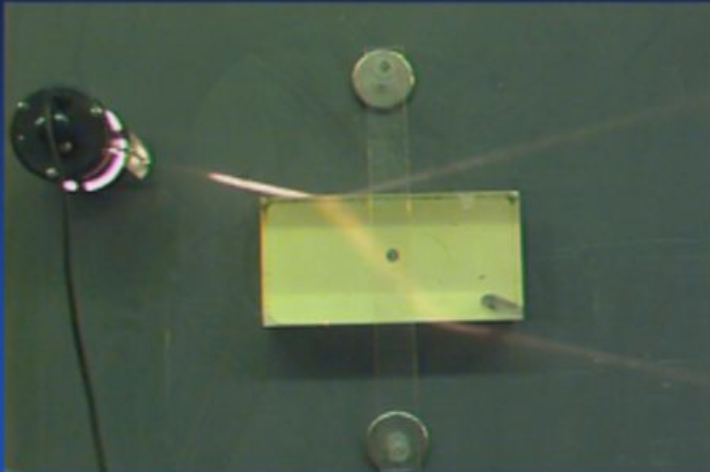
Robert Hooke

Christiaan Huygens

- A ray of light =
A wave



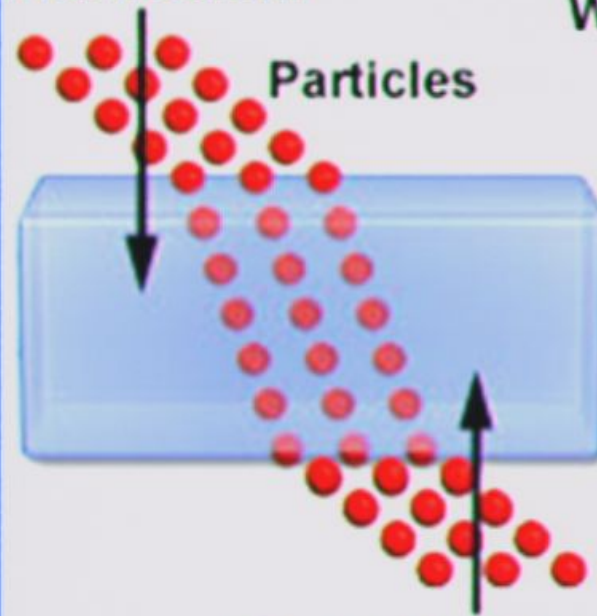
Refraction



Refraction

Refraction of Particles and Waves

Force Pulls
Particles
into Medium



Opposite Force
Pulls Particles

Waves

Wave Edge
Bends at
Entry



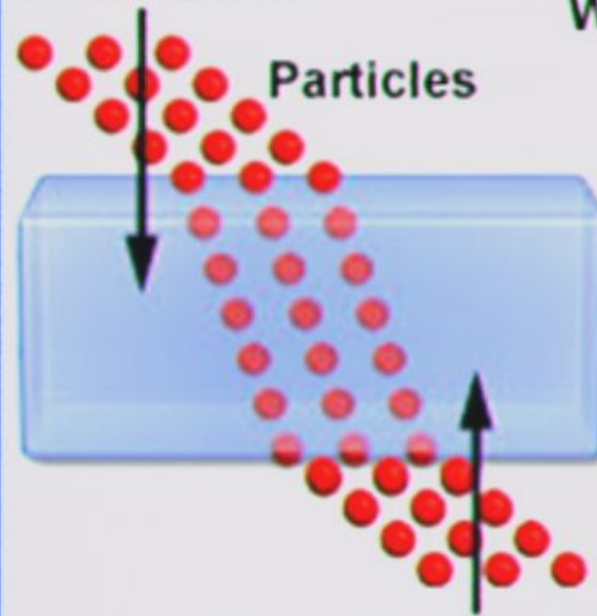
Wave Edge
Bends at
Exit

Figure 1

Refraction

Refraction of Particles and Waves

Force Pulls
Particles
into Medium



Particles

Waves

Wave Edge
Bends at
Entry



Wave Edge
Bends at
Exit

Opposite Force
Pulls Particles

Figure 1

Particle theory: light travels faster in a medium

Wave theory: light travels slower in a medium

Particle theory: light travels faster in a medium

Wave theory: light travels slower in a medium

Experiment is a judge:

Particle theory: light travels faster in a medium

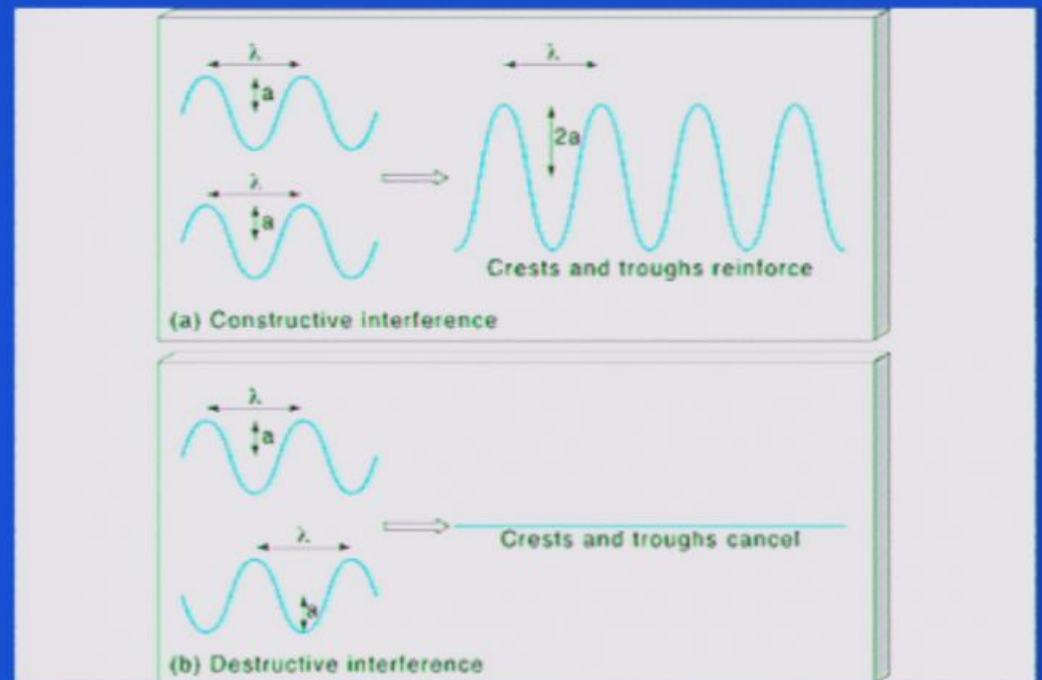
Wave theory: light travels slower in a medium

Experiment is a judge:

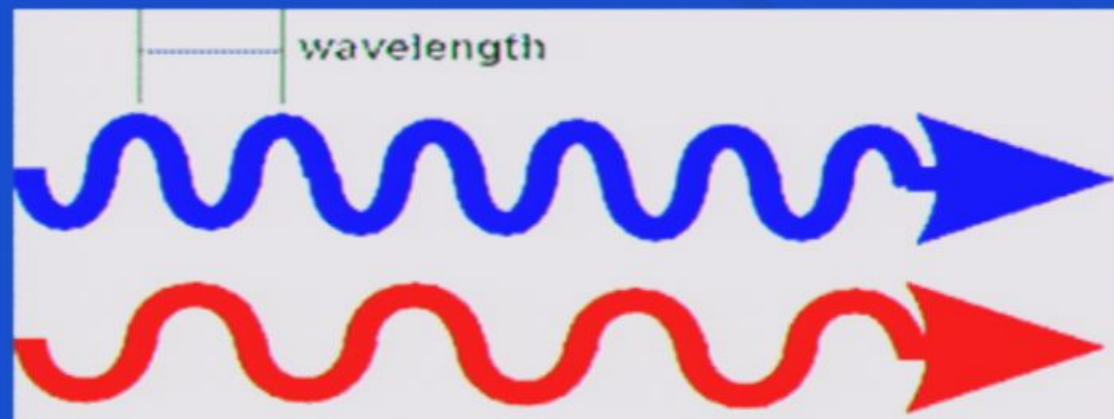
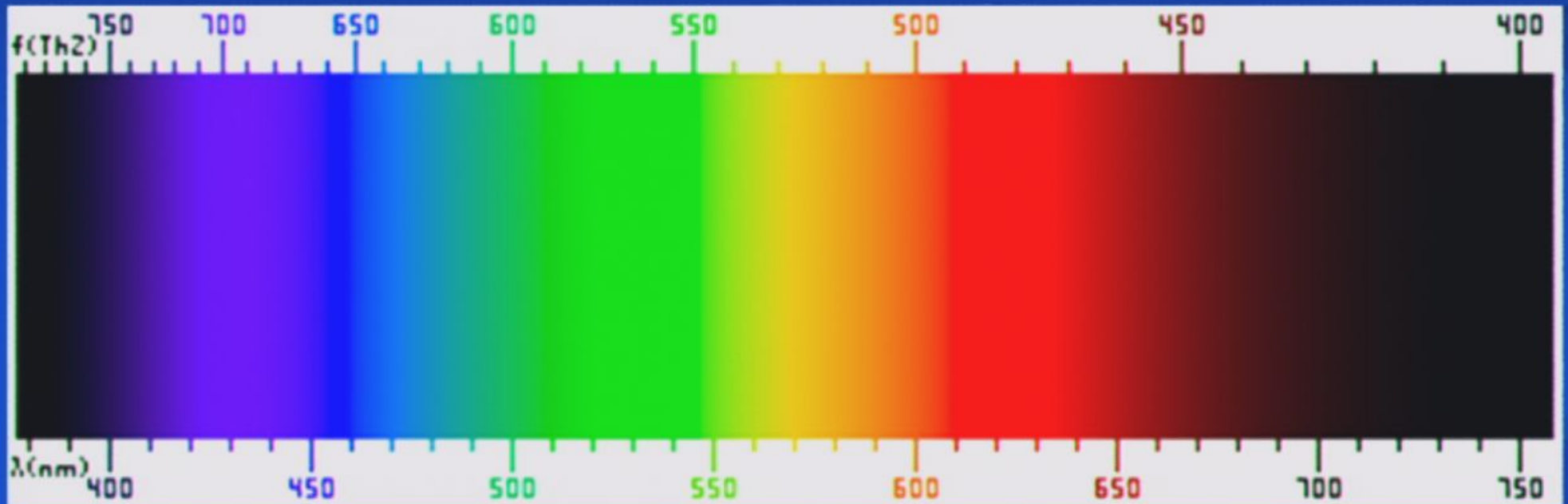
Wave theory wins

since the measured velocity of light is slower
in a medium

Wave theory has some remarkable predictions



Now we understand what is color



If light is a wave, what is waving?



- If vacuum is empty, nothing can wave. It is much easier to regard light as a beam of particles.
- But light is a wave \Rightarrow Vacuum is not empty
Such a “vacuum” media is called ***ether***

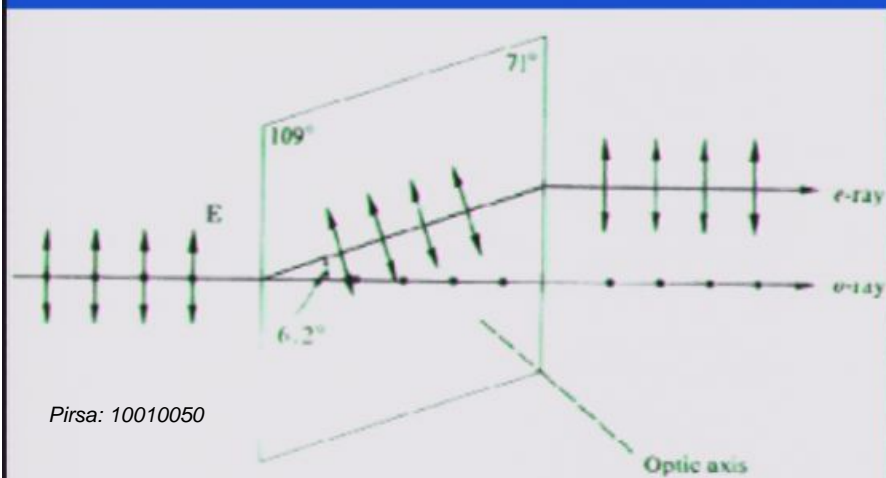
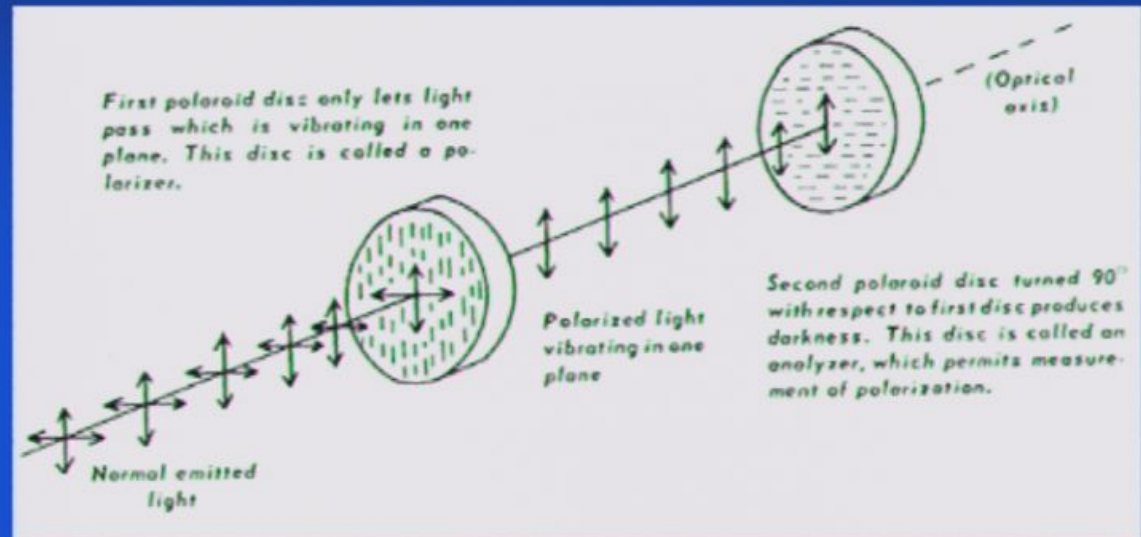
Vacuum is like a ocean

- Light = a wave in ocean

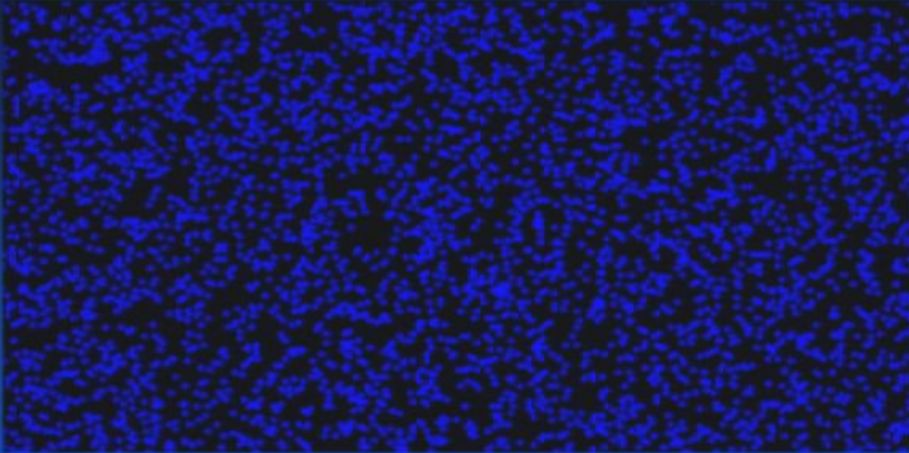
But this is not the end of story



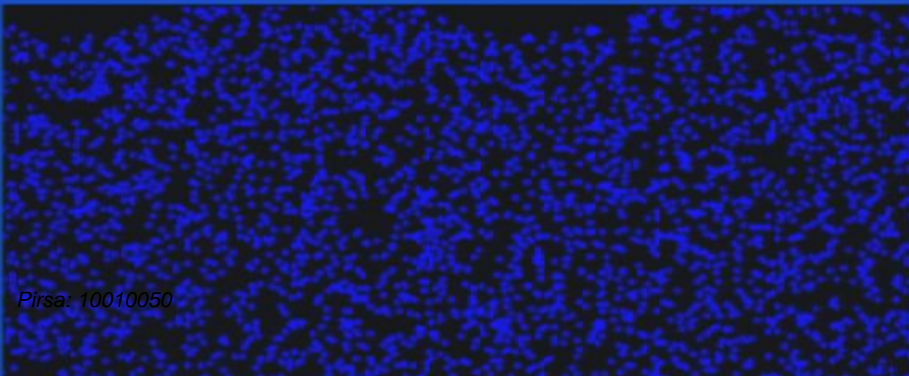
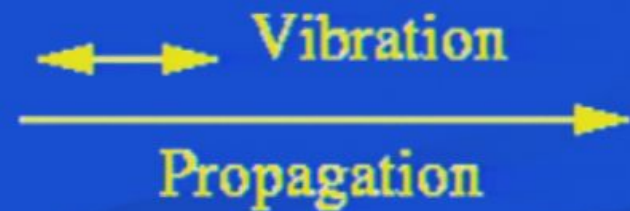
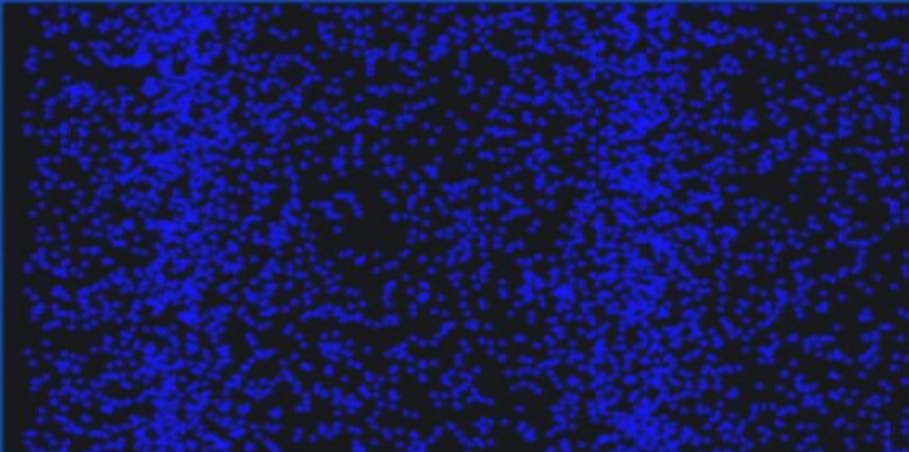
But this is not the end of story



Two kinds of waves
Two directions of
oscillations - polarizations

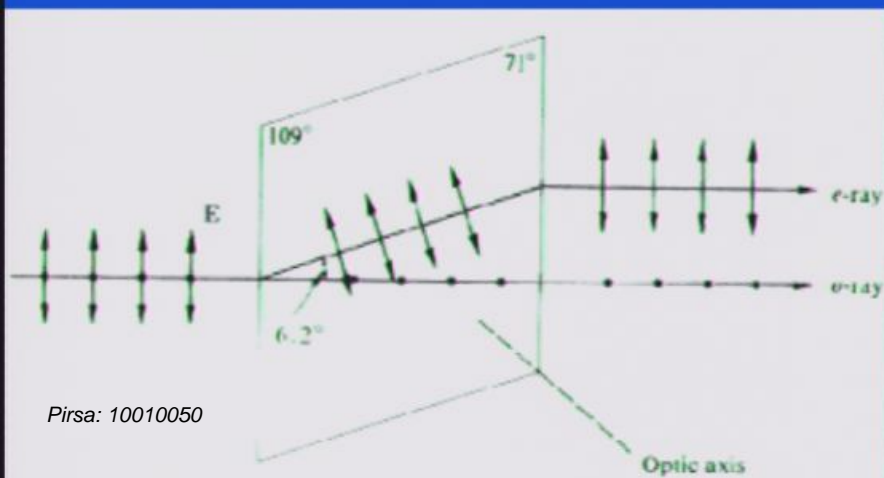
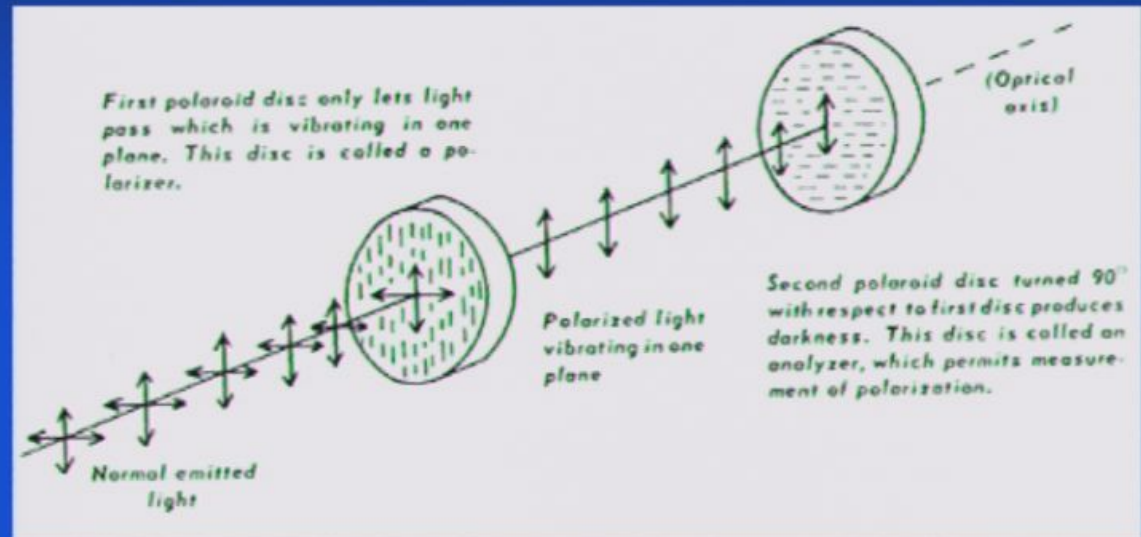


Vacuum “ocean”
cannot be a liquid

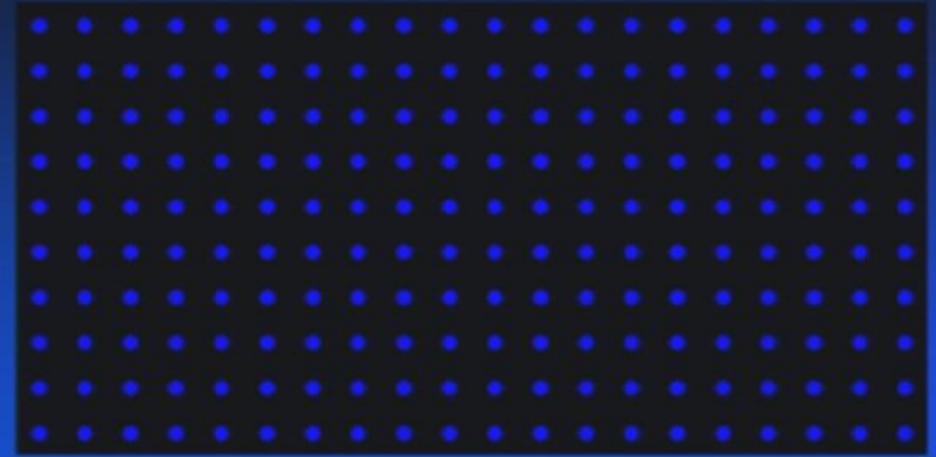
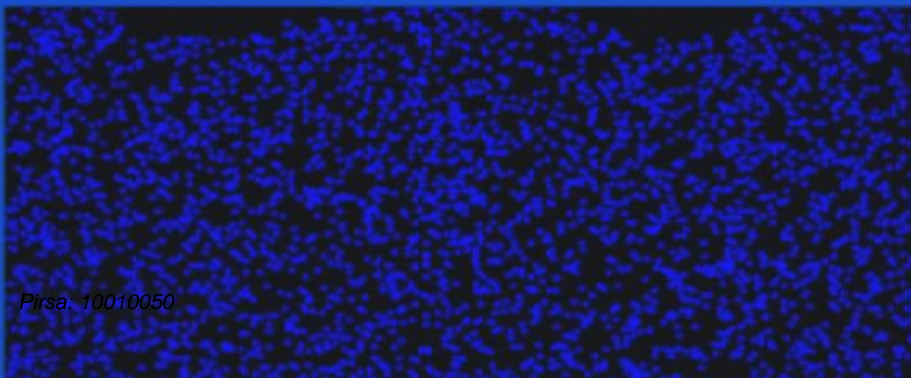
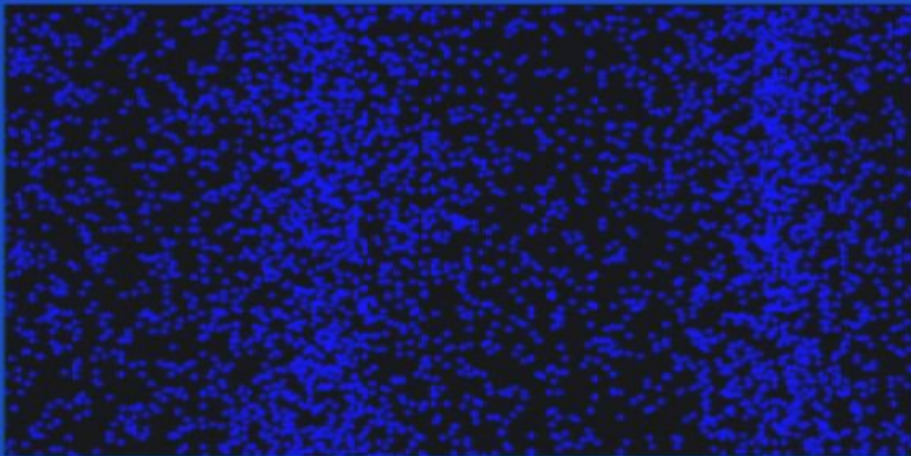
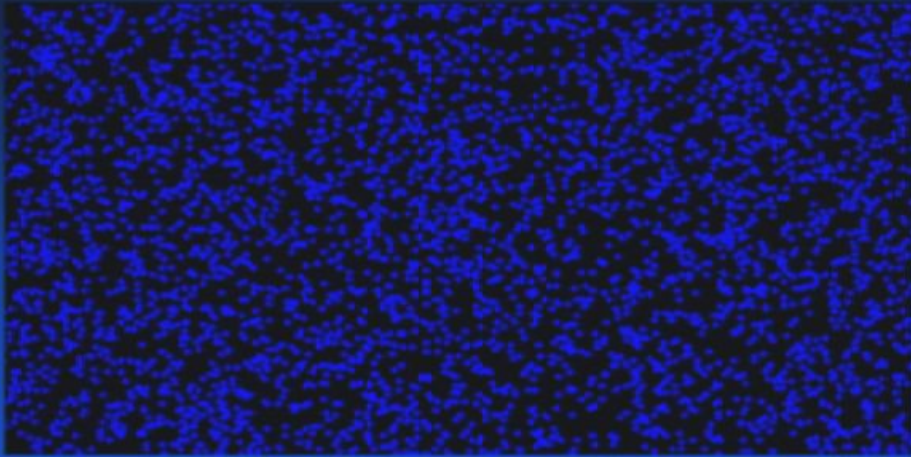


Wave in liquid has
only one longitudinal
polarization

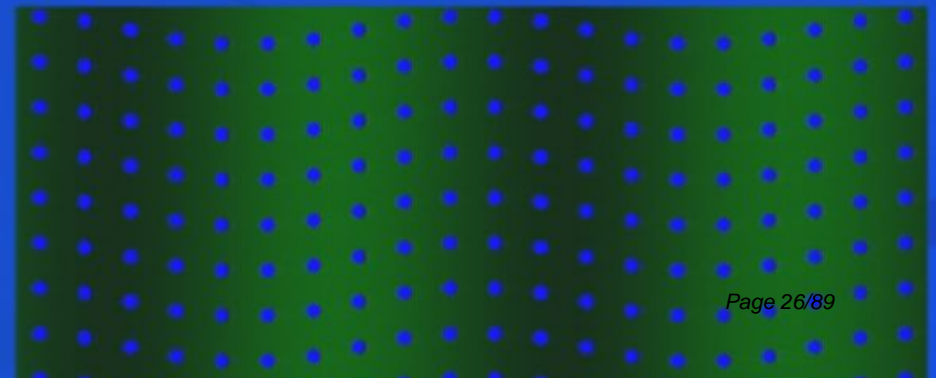
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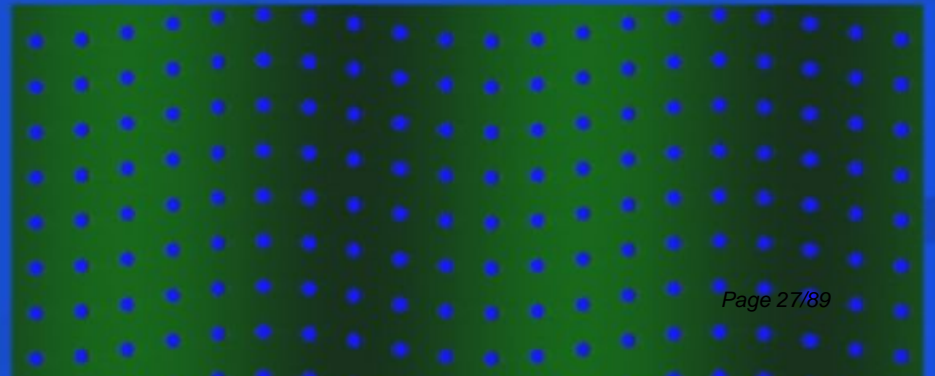
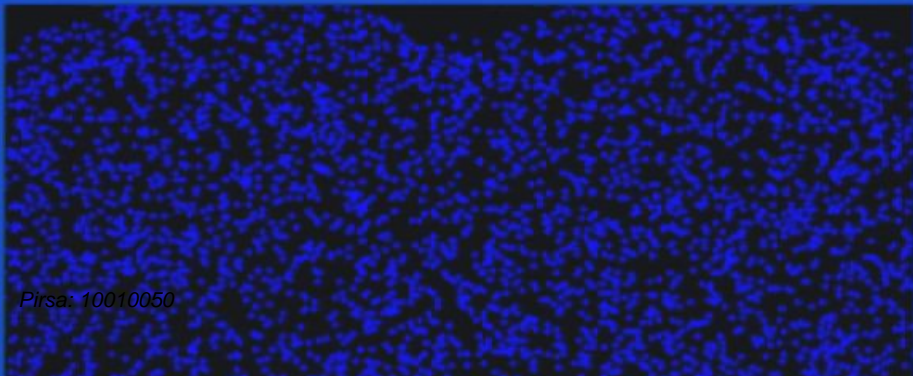
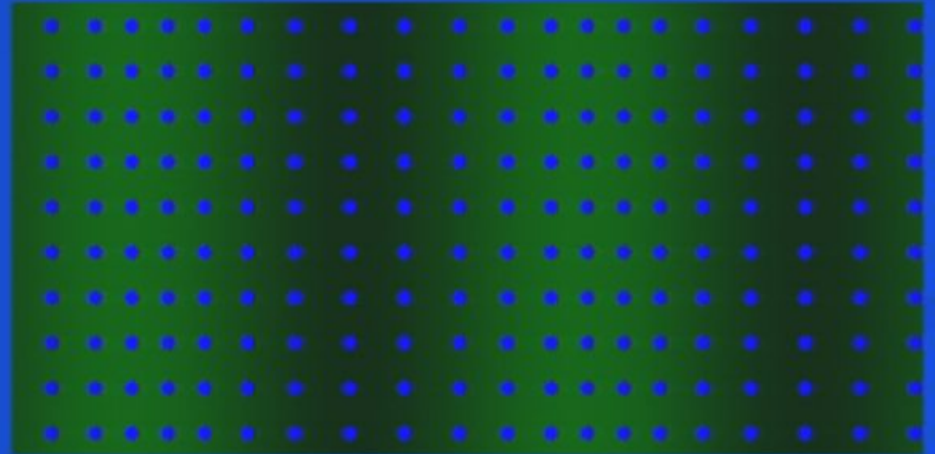
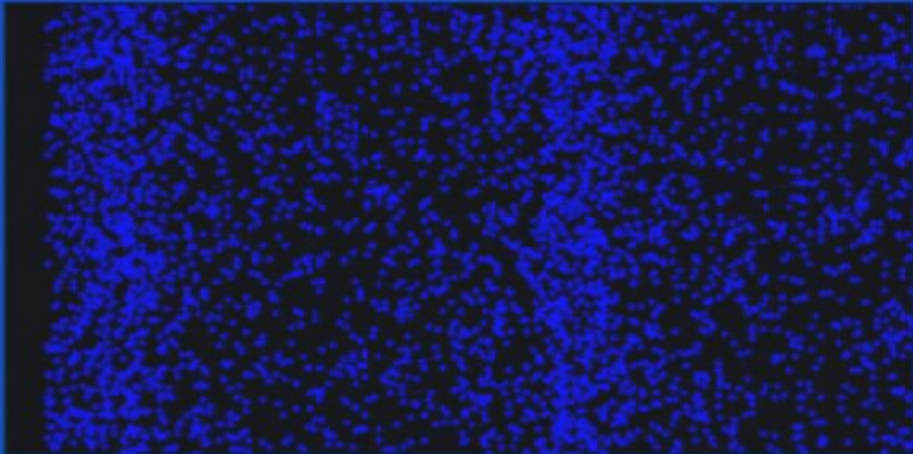
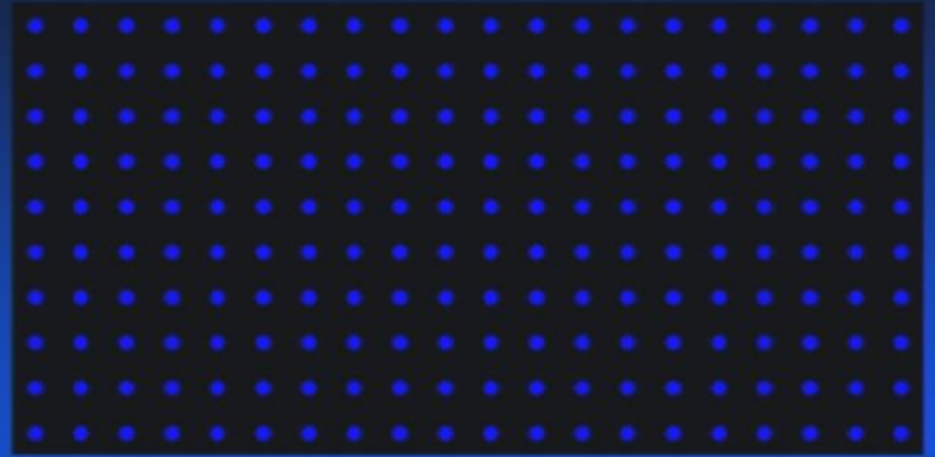
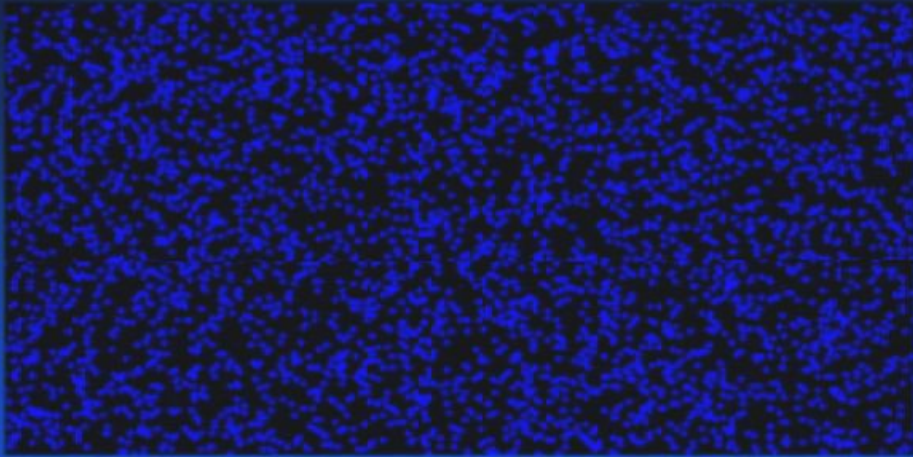


Two kinds of waves
Two directions of
oscillations - polarizations



Wave in crystal has
Two transverse
polarizations





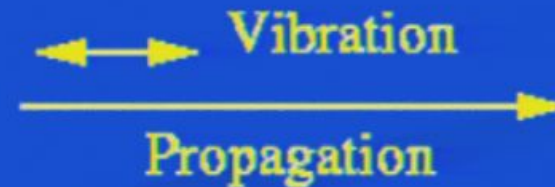
- Light wave has two transverse modes only



- Light wave has two transverse modes only



- Ether cannot be a liquid:
Wave in liquid has one longitudinal mode



- Light wave has two transverse modes only



- Ether cannot be a liquid:
Wave in liquid has one longitudinal mode



- Ether cannot be a crystal:
Wave in crystal has one longitudinal mode
two transverse modes



**Light is a wave
but what vibration leads to light wave?**

**Light is a wave
but what vibration leads to light wave?**

For a long time, we do not know

Light is a wave
but what vibration leads to light wave?

For a long time, we do not know

But we manage to obtain
a theory of light wave

Light is a wave
but what vibration leads to light wave?

For a long time, we do not know

But we manage to obtain
a theory of light wave

The break through comes

Magnetism



Magnetism



Magnetism



Magnetism



Magnetism



Magnetism



Magnetism



Magnetism



Magnetism



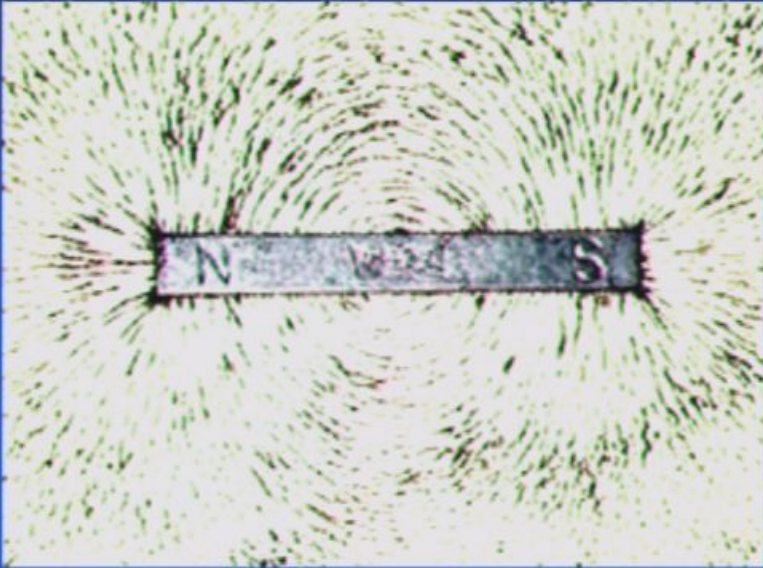
Magnetism



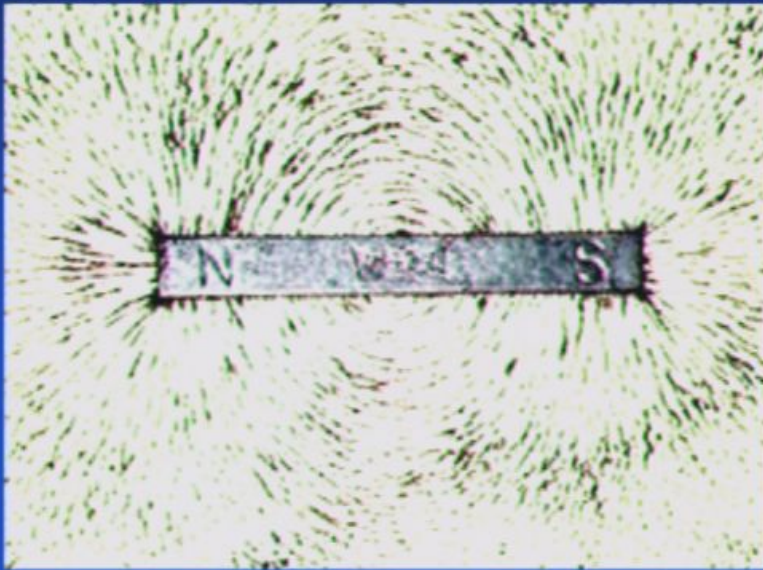
Magnetism



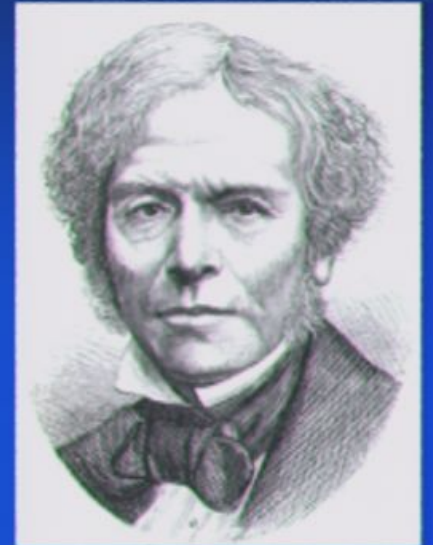
Magnetic field



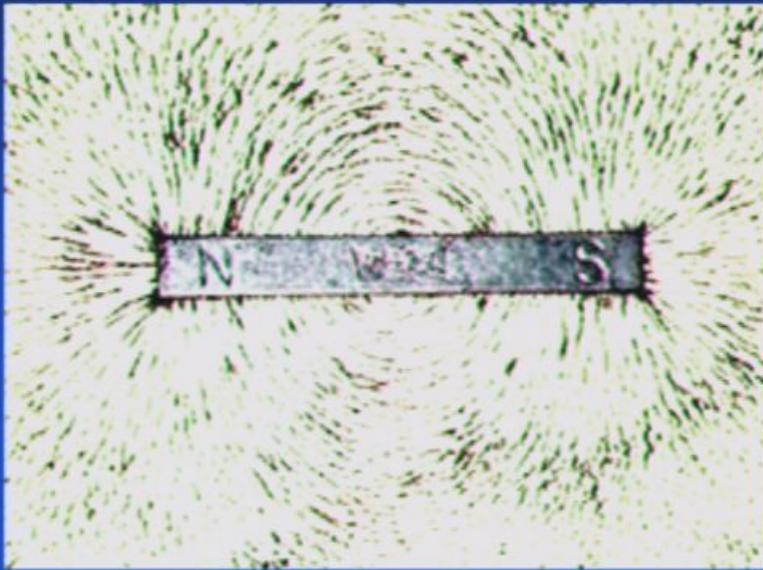
Magnetic field



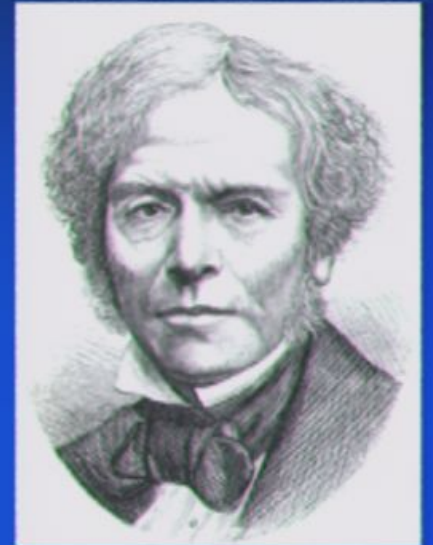
Magnetic field
in vacuum
-- Faraday



Magnetic field



Magnetic field
in vacuum
-- Faraday



Electricity and electric field

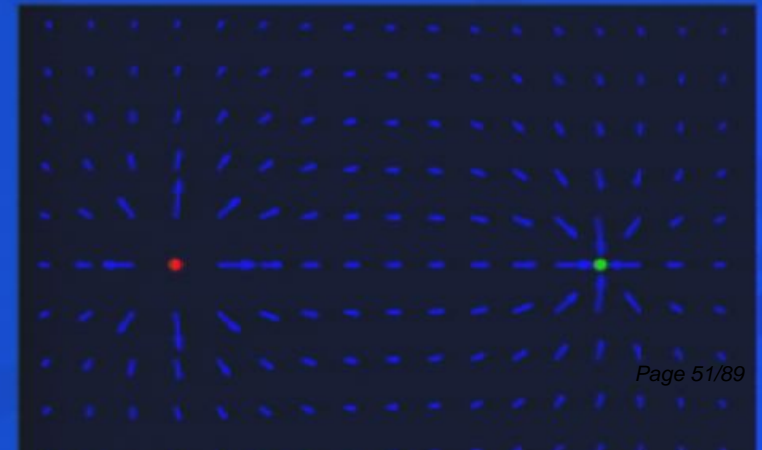


Electricity and electric field

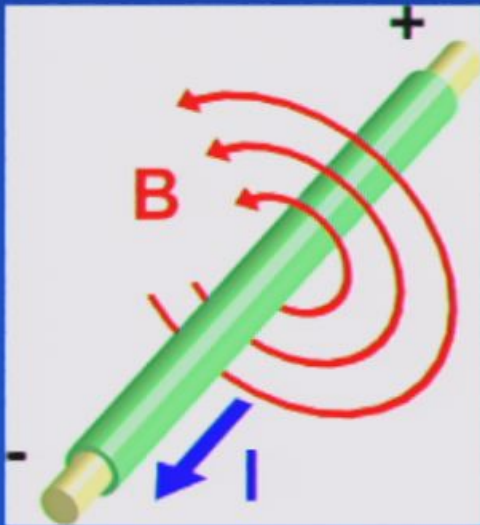


The Latin word, electricus, means to "produce from amber by friction."

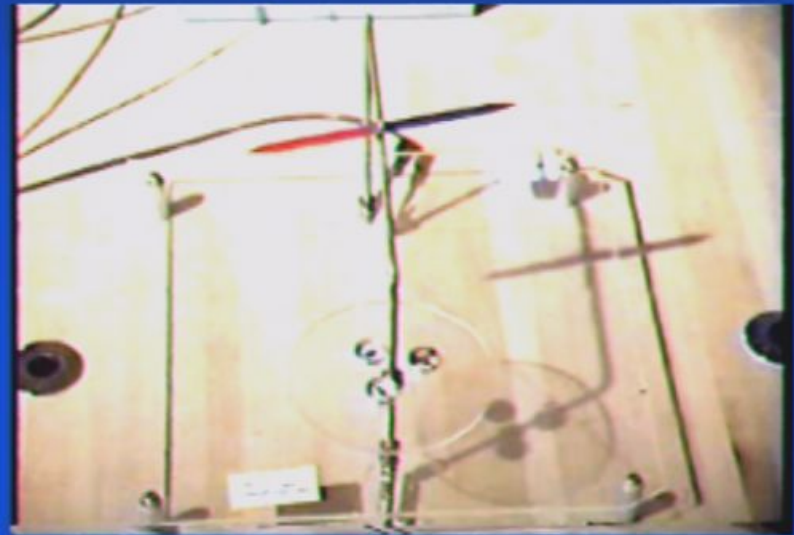
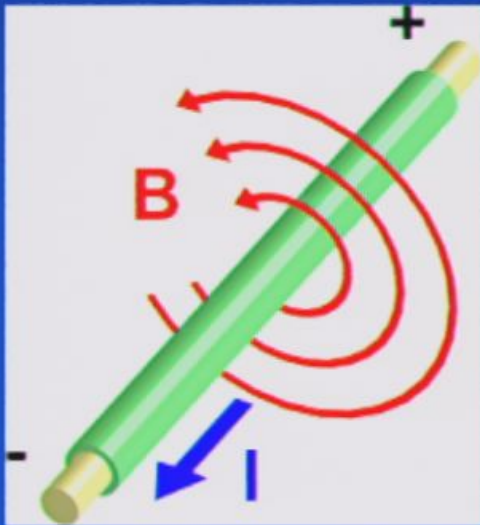
Electricity and electric field



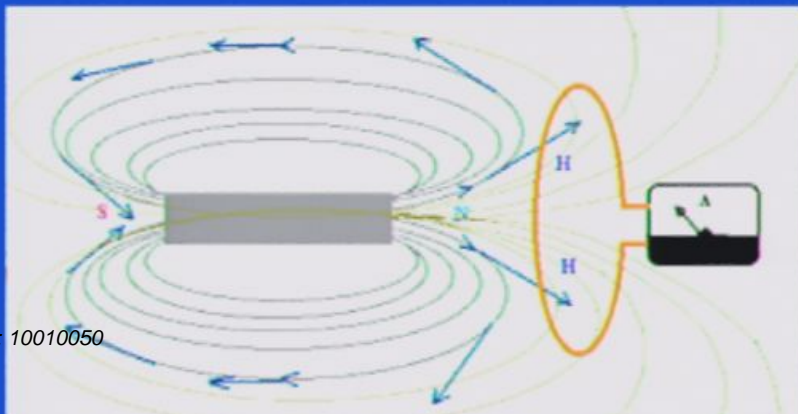
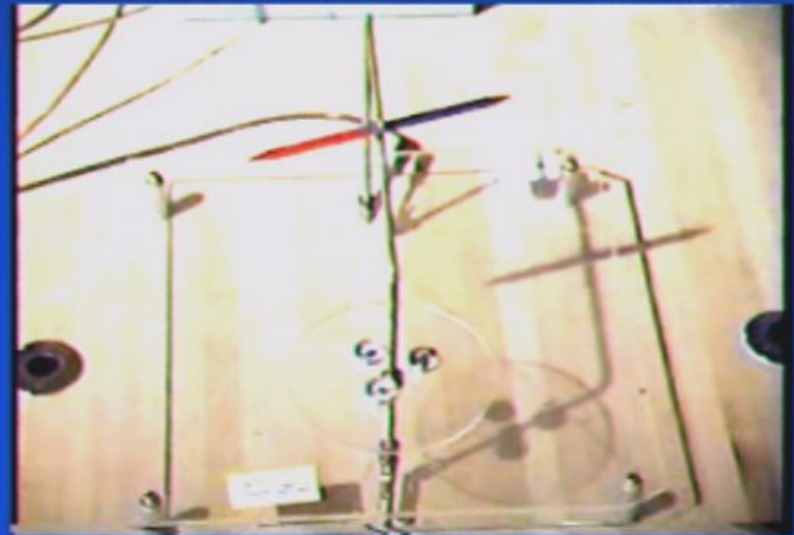
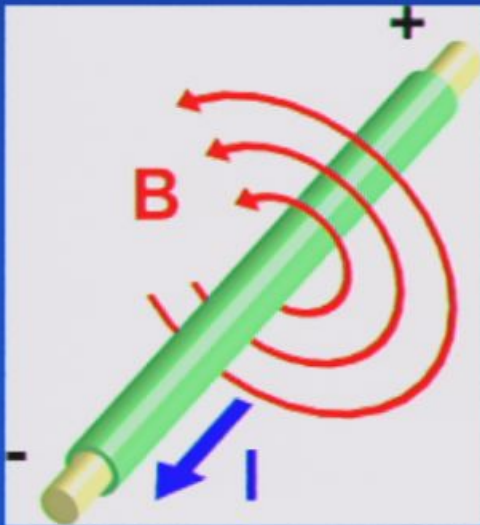
The unification of electricity and magnetism



The unification of electricity and magnetism

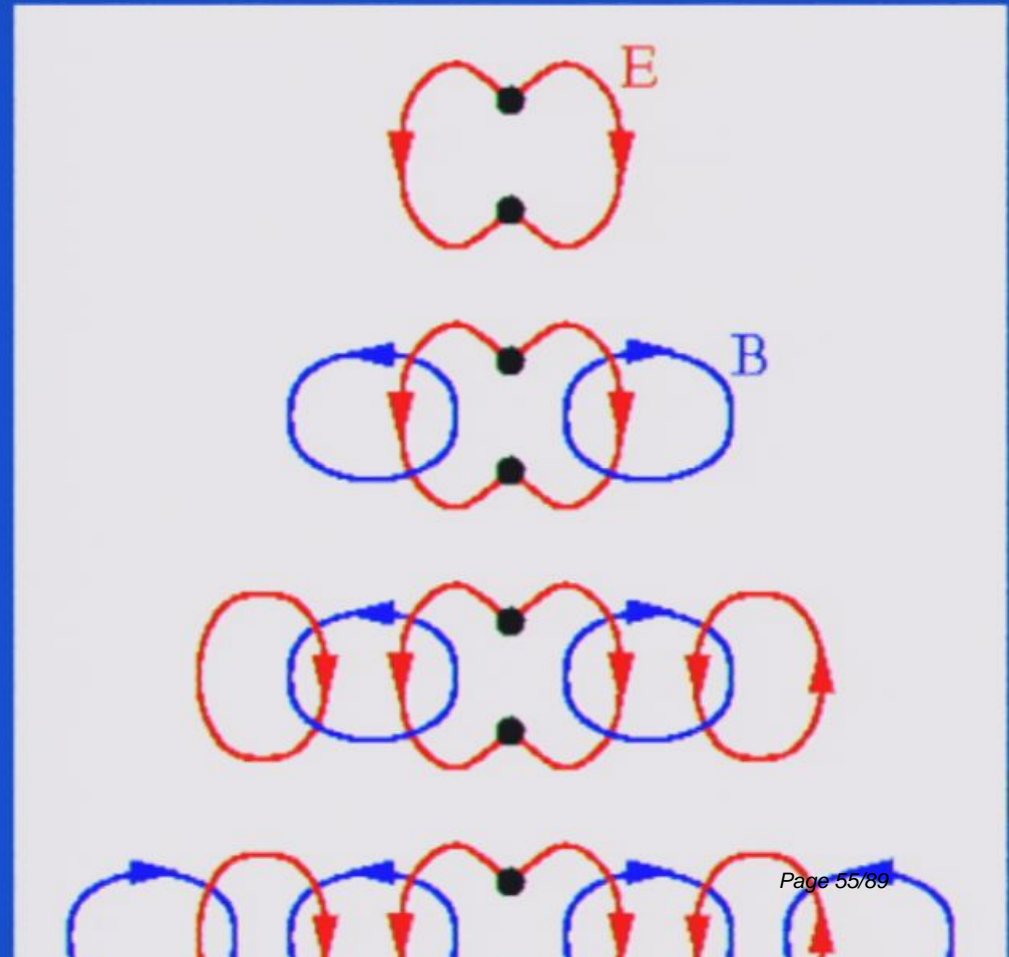


The unification of electricity and magnetism



Mutual induction \Rightarrow electromagnetic wave

Wave of electric and
magnetic fields =
electromagnetic wave



Electromagnetic wave and light

Maxwell found that electromagnetic wave and light wave have the same velocity.

He proposed that

Electromagnetic wave = light wave

Electromagnetic wave and light

Maxwell found that electromagnetic wave and light wave have the same velocity.

He proposed that

Electromagnetic wave = light wave

Electricity, magnetism, and light are unified

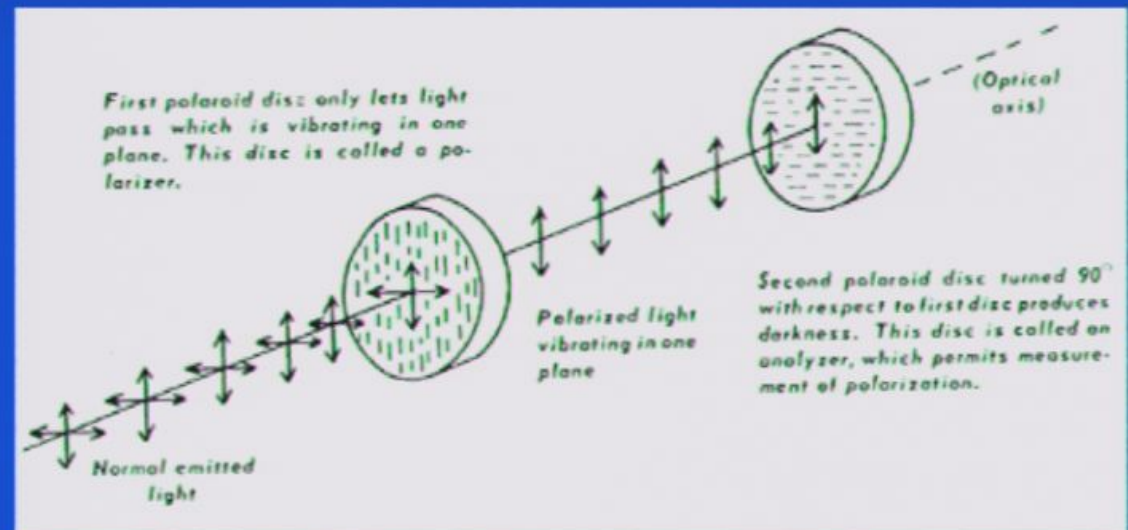
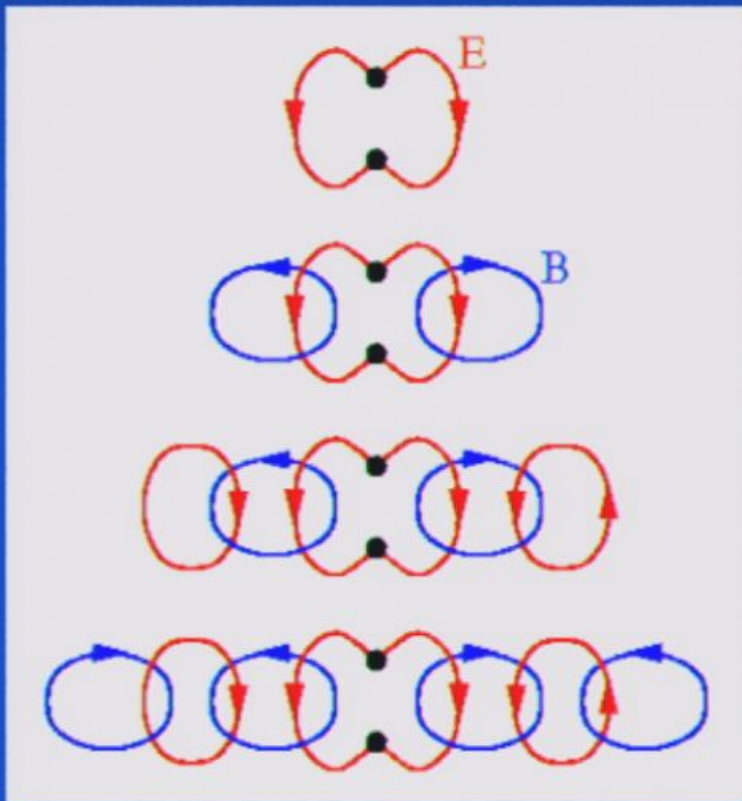


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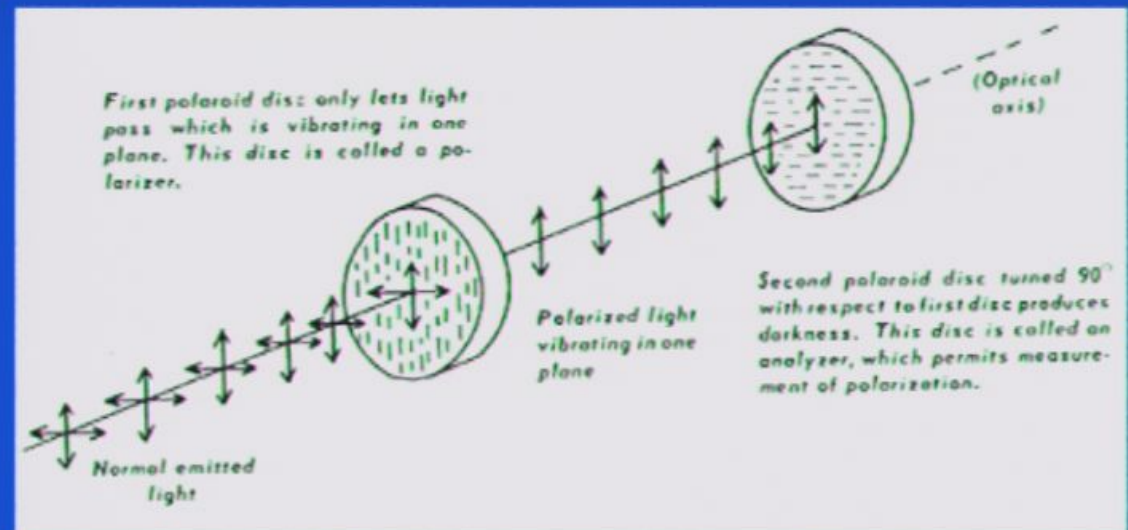
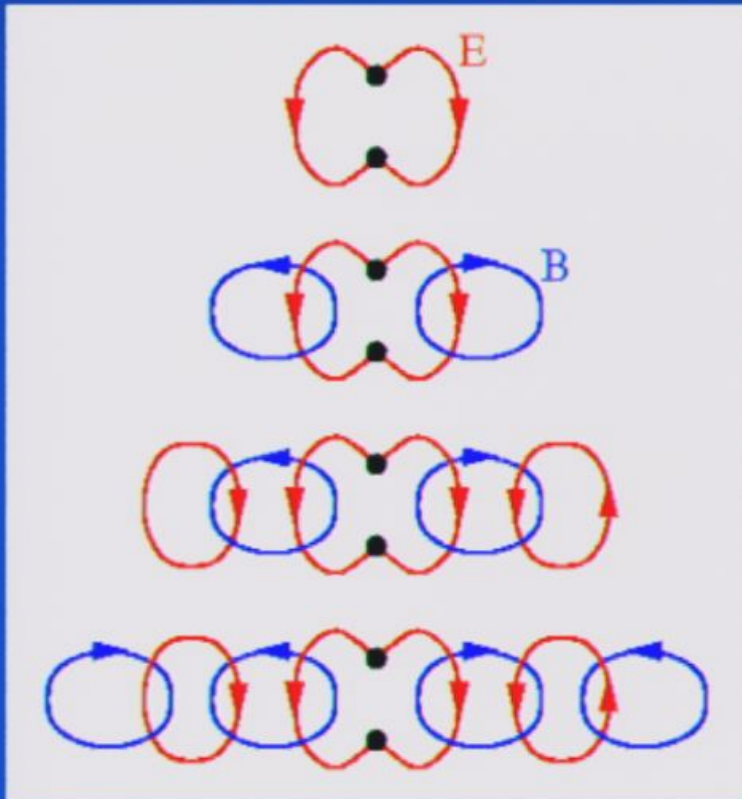


Page 57/89

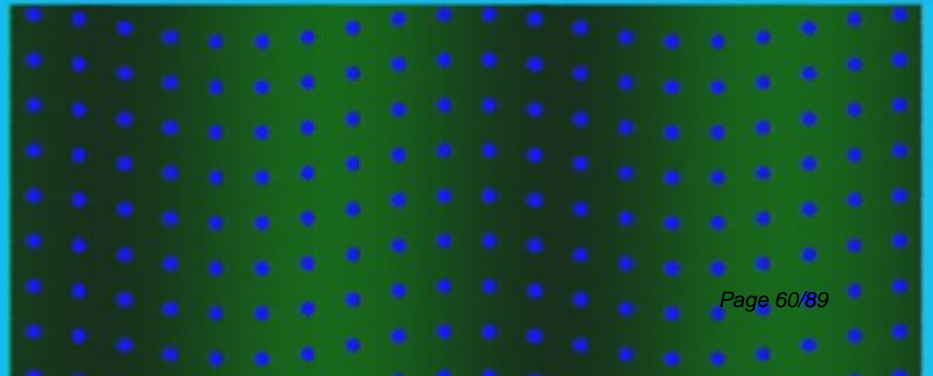
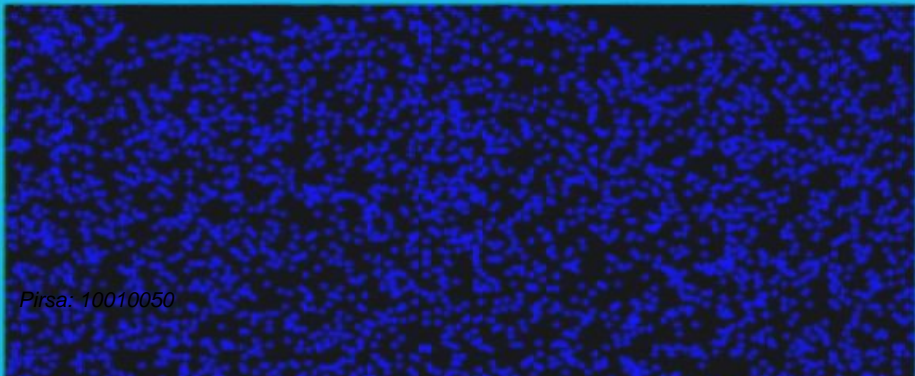
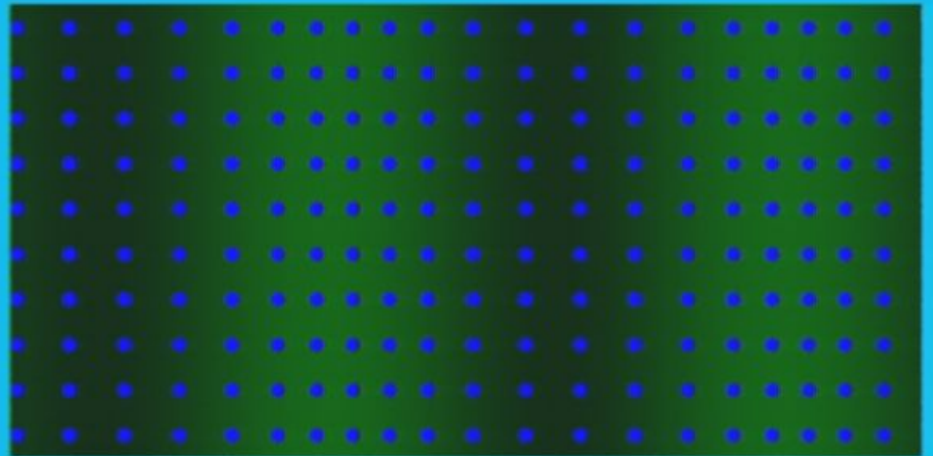
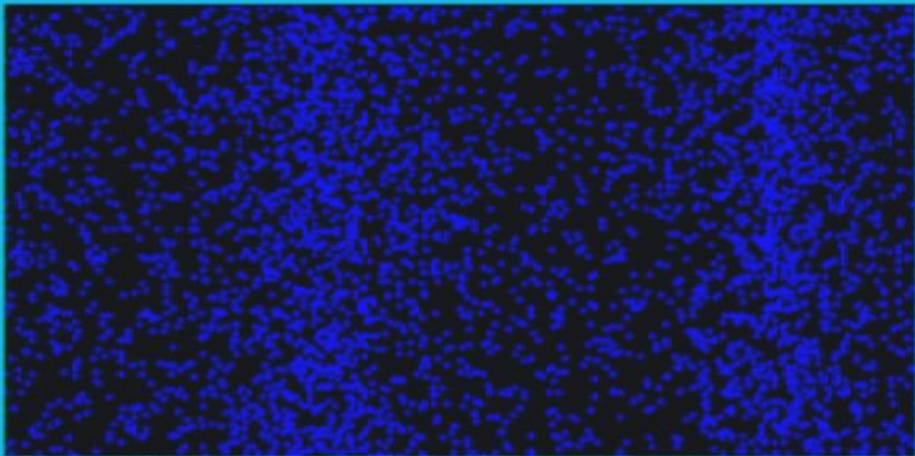
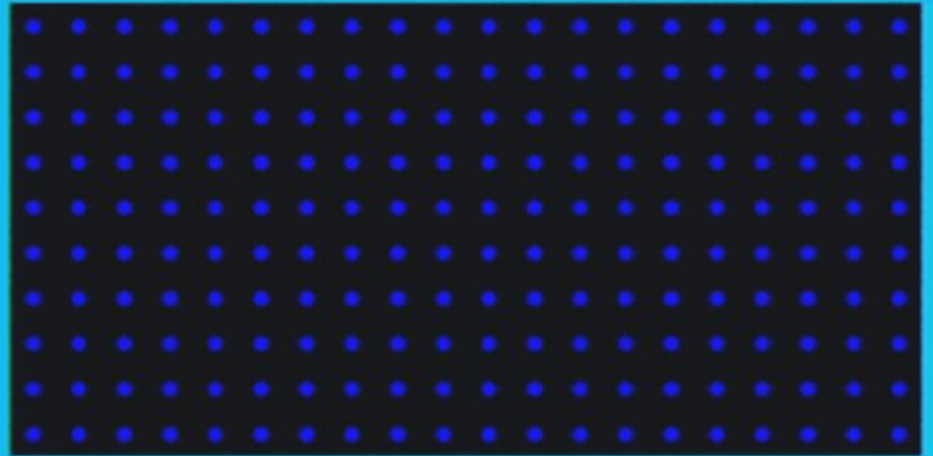
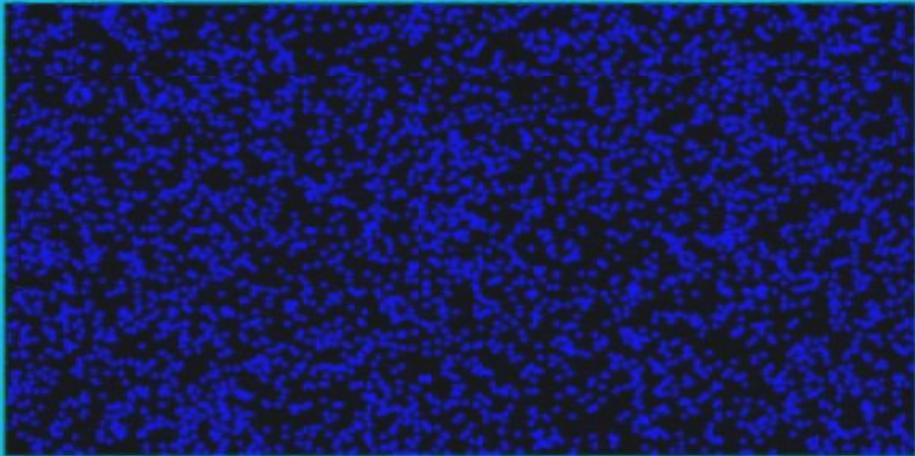
Electromagnetic theory explain the polarizations of light



Electromagnetic theory explain the polarizations of light



But the vibration of what give rise to
electric field **E** and magnetic field **B**?



sin $R^a_{bcd} = \Gamma^a_{bd,c} - \Gamma^a_{bc,d}$
 $+ \Gamma^a_{ce} \Gamma^e_{db} - \Gamma^a_{de} \Gamma^e_{cb}$
 $- C^e_{cd} \Gamma^a_{eb}$

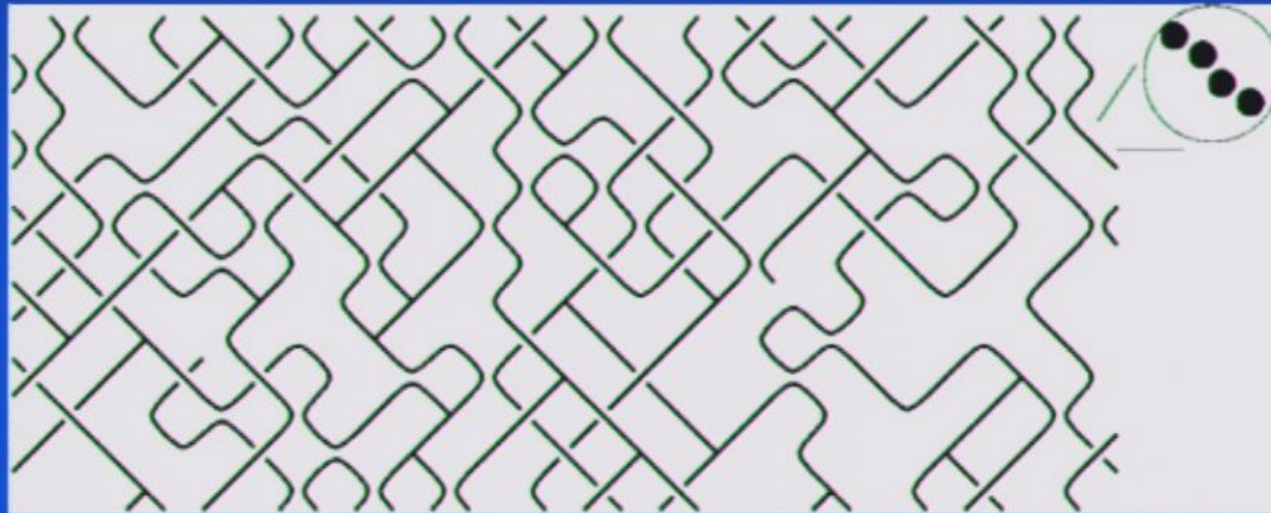
$$\partial_t^2 \rho - v^2 \nabla^2 \rho = 0$$

$$\partial_t^2 u^l - C^l_{ijk} \nabla_i \nabla_j u^k = 0$$

How should particles organize to produce wave with only two transverse modes?

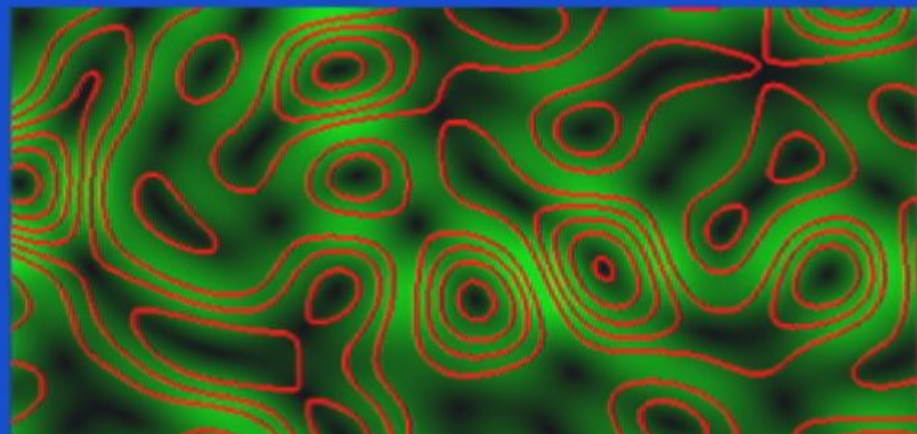
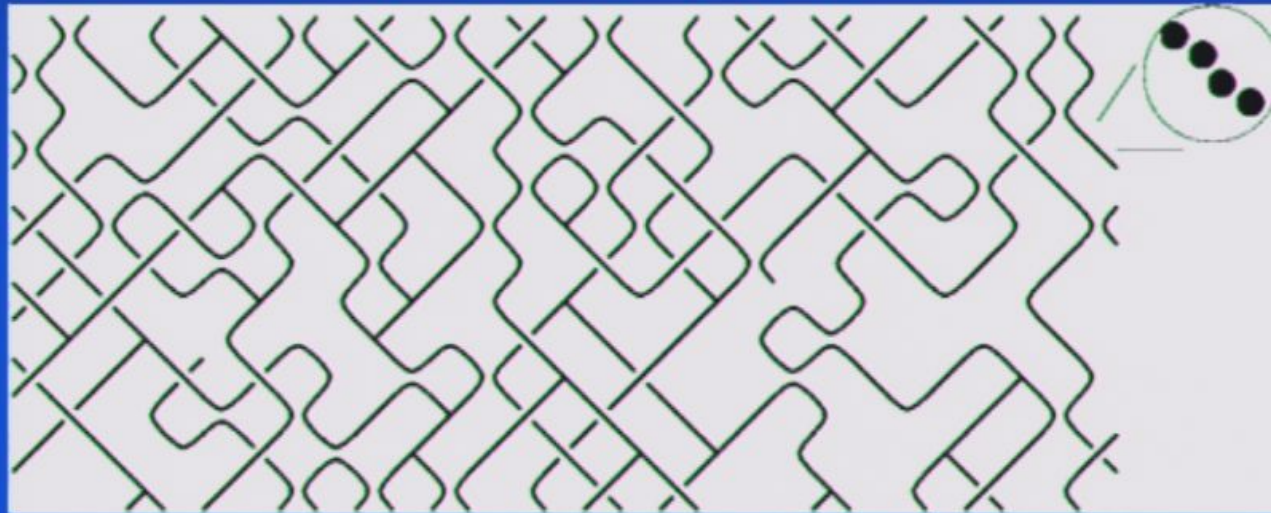
How should particles organize to produce wave with only two transverse modes?

- Particle form strings
- Strings fill the space



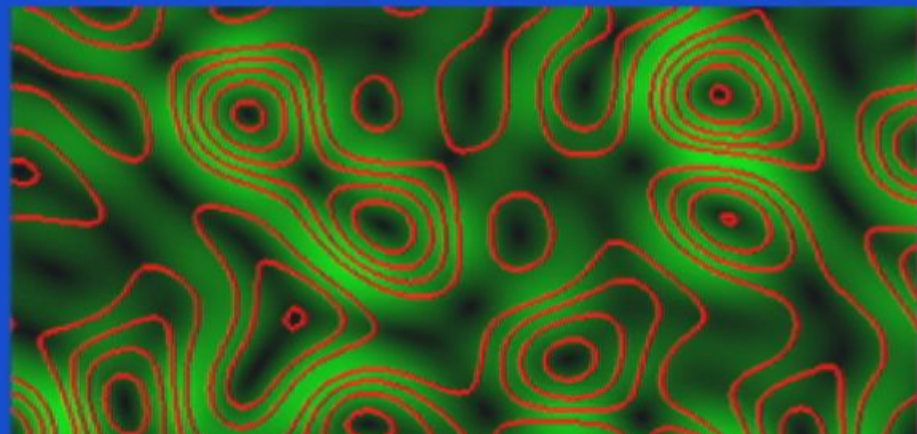
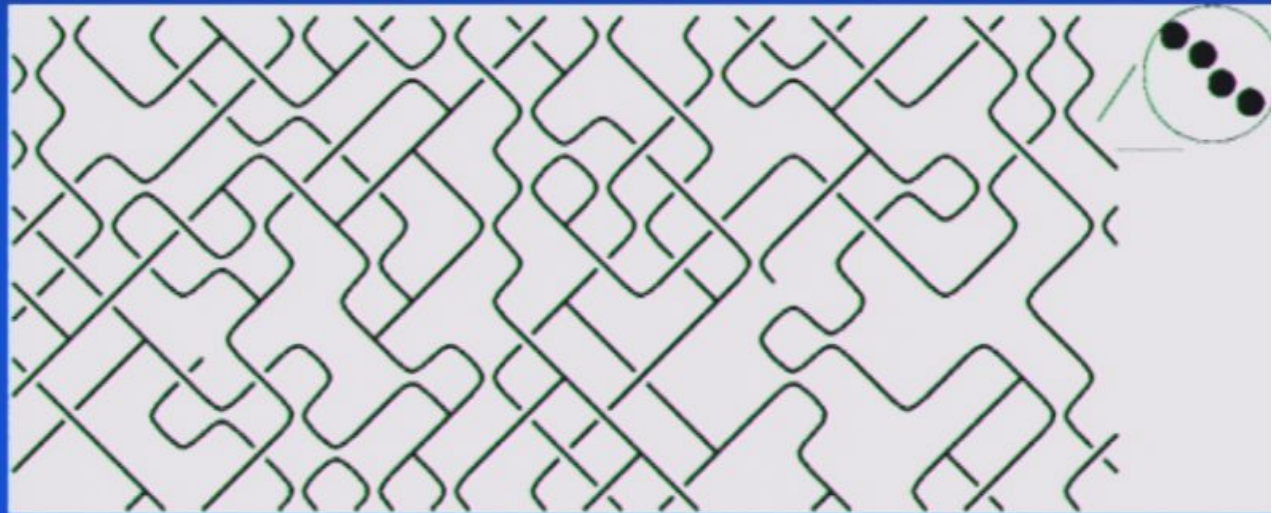
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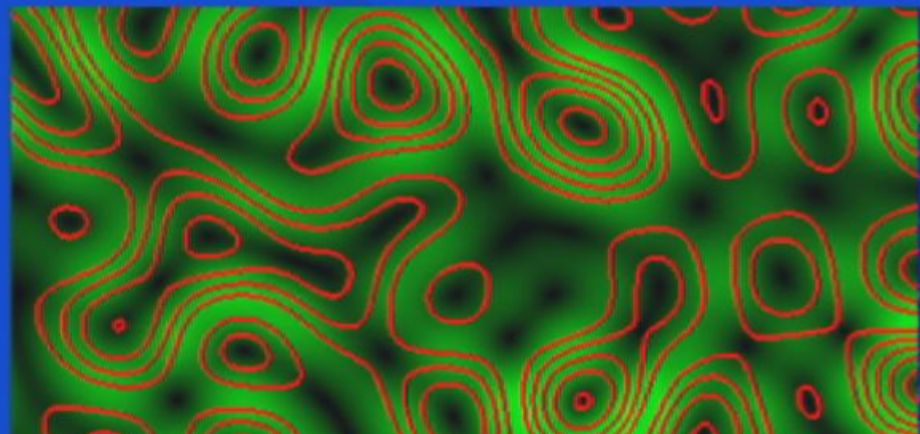
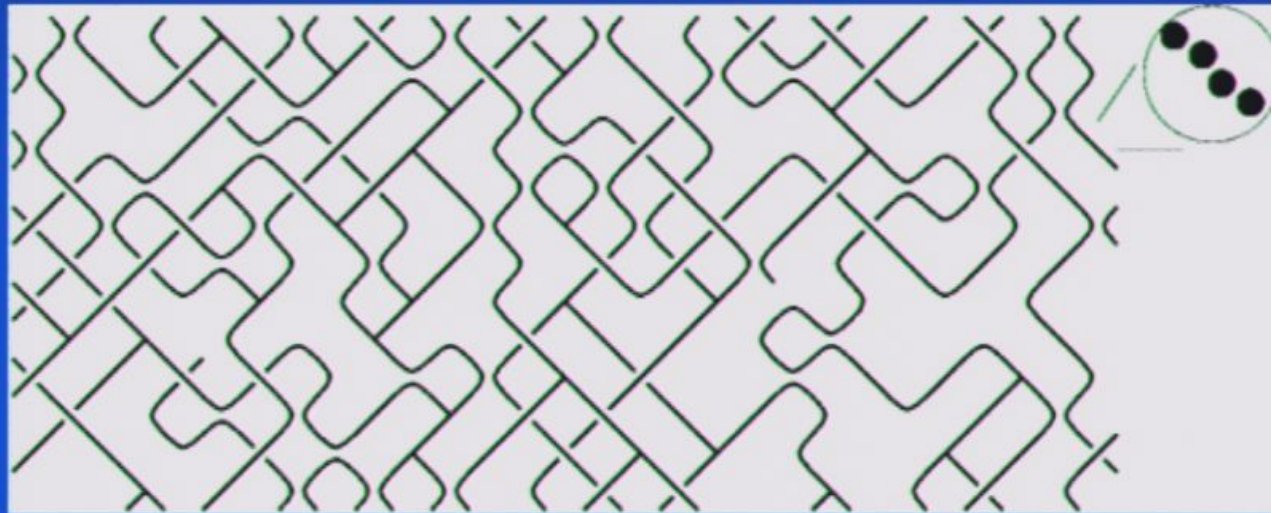
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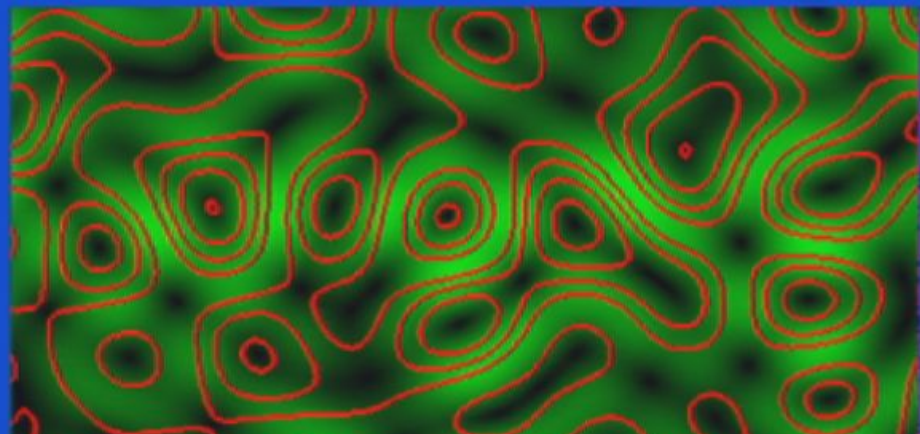
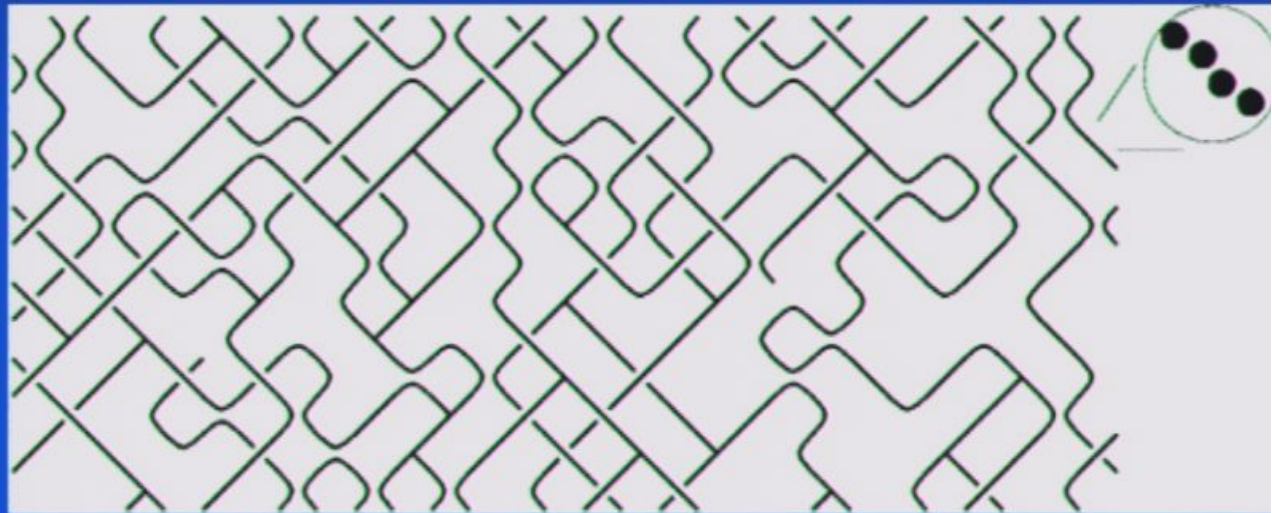
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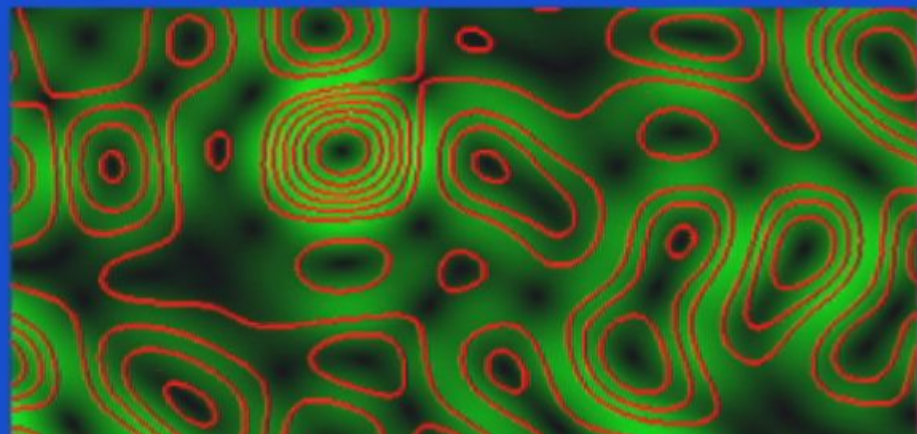
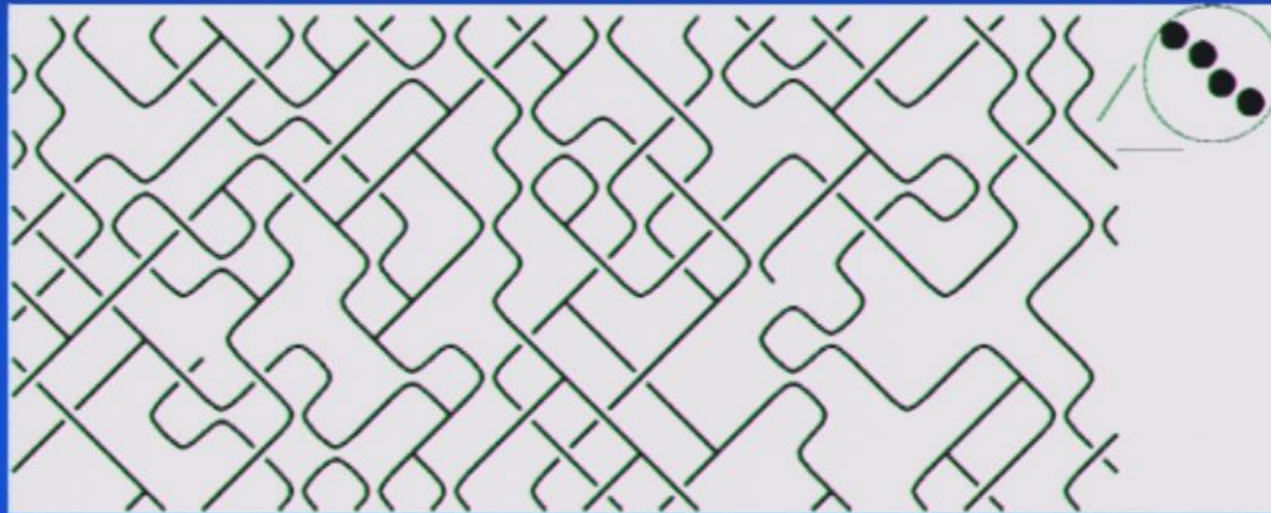
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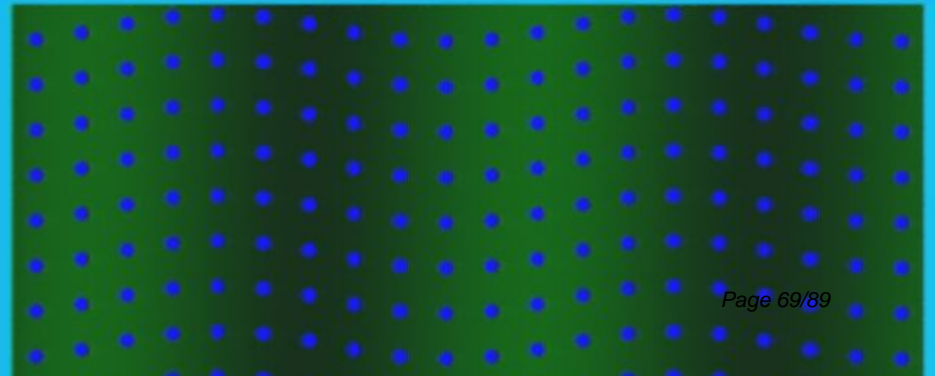
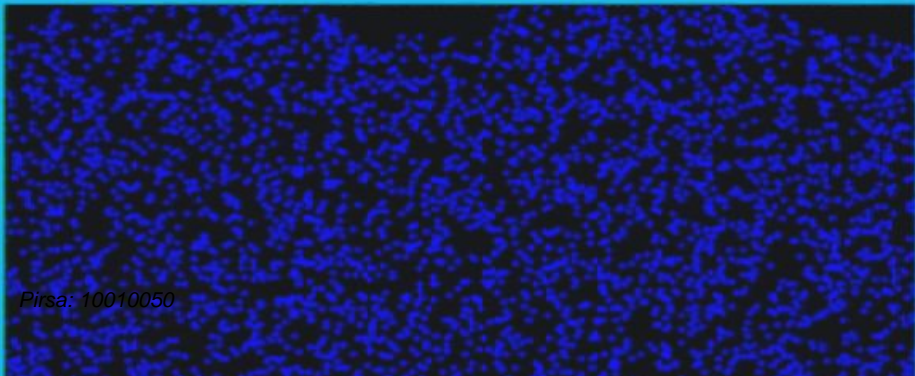
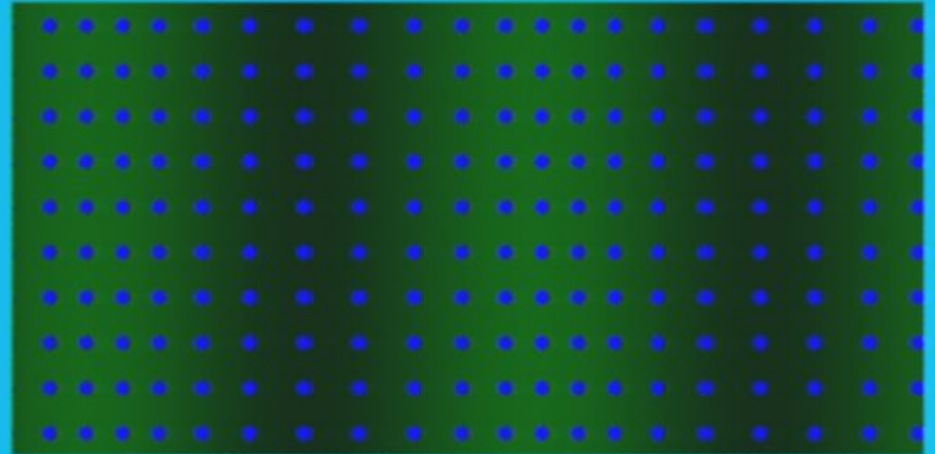
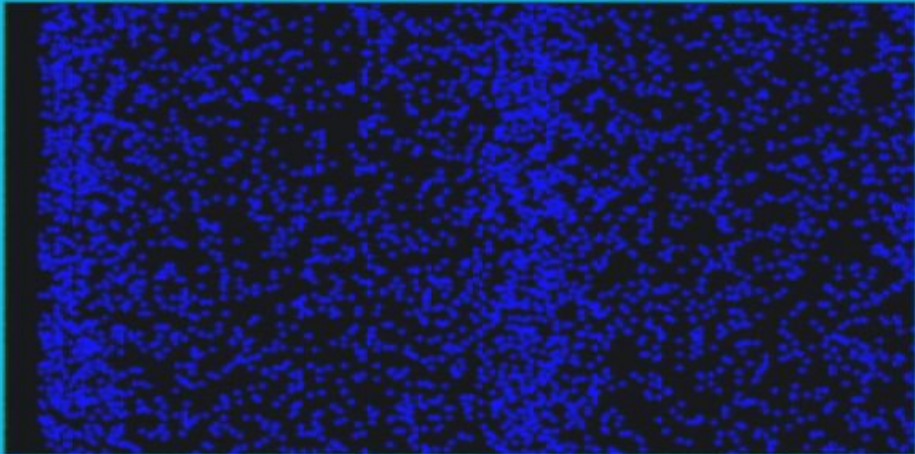
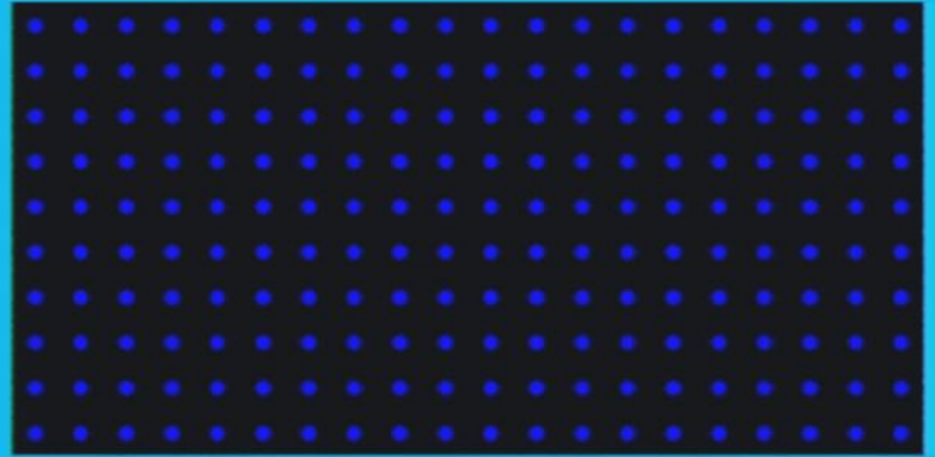
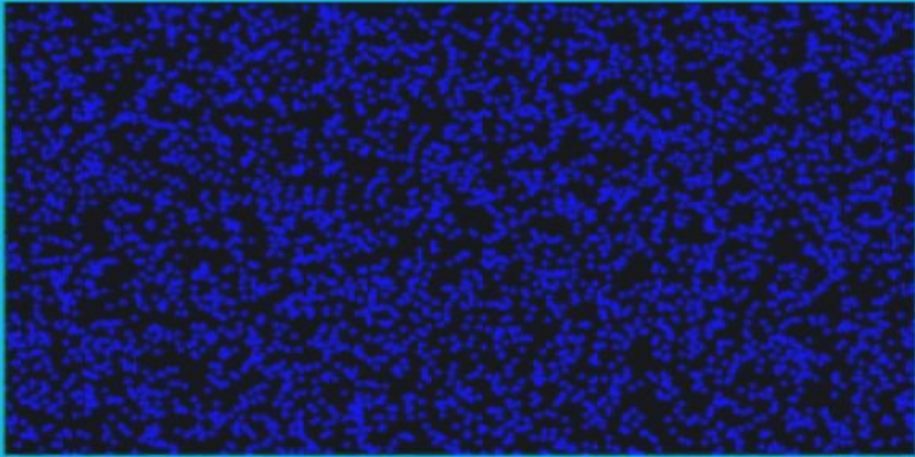
- Particle form strings
- Strings fill the space
- Strings from a liquid state



How should particles organize to produce wave with only two transverse modes?

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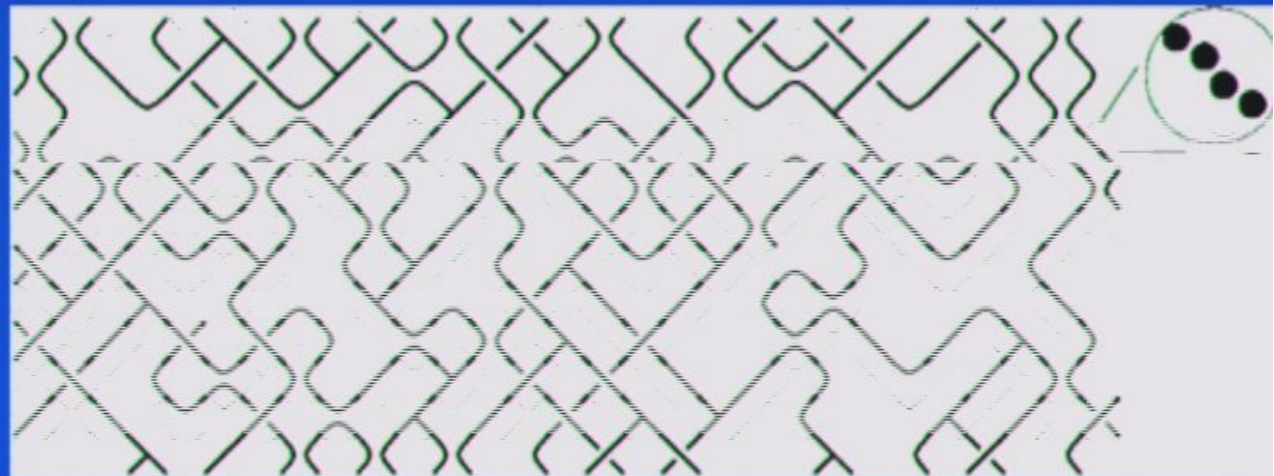




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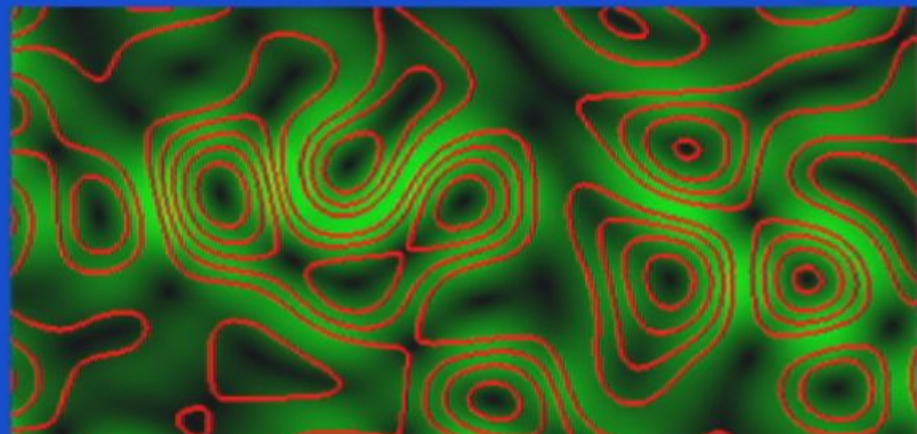
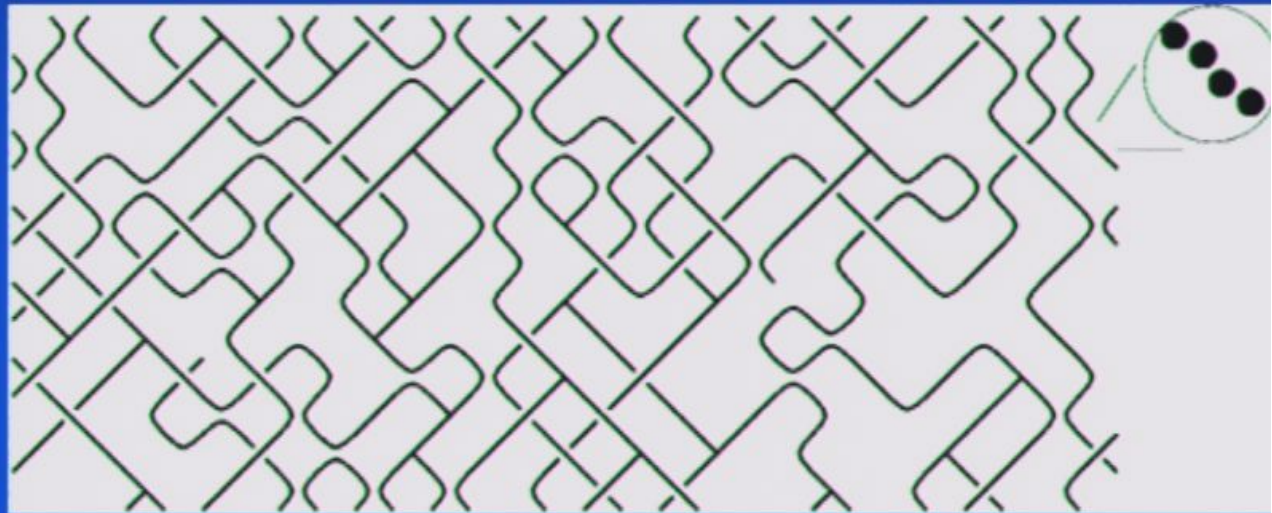
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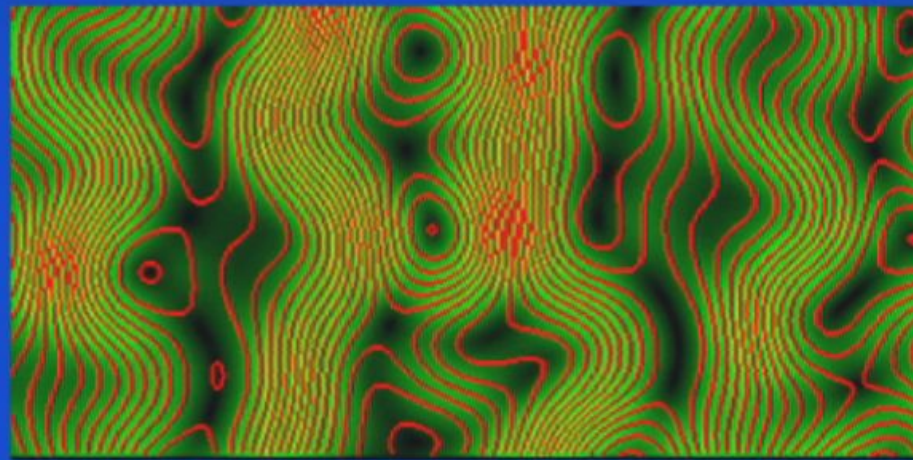


How should particles organize to produce wave with only two transverse modes?

- Particle form strings
- Strings fill the space
- Strings from a liquid state



Wave in string liquid = light wave
= electromagnetic wave



Density of strings = strength of electric field

Direction of strings = direction of electric field

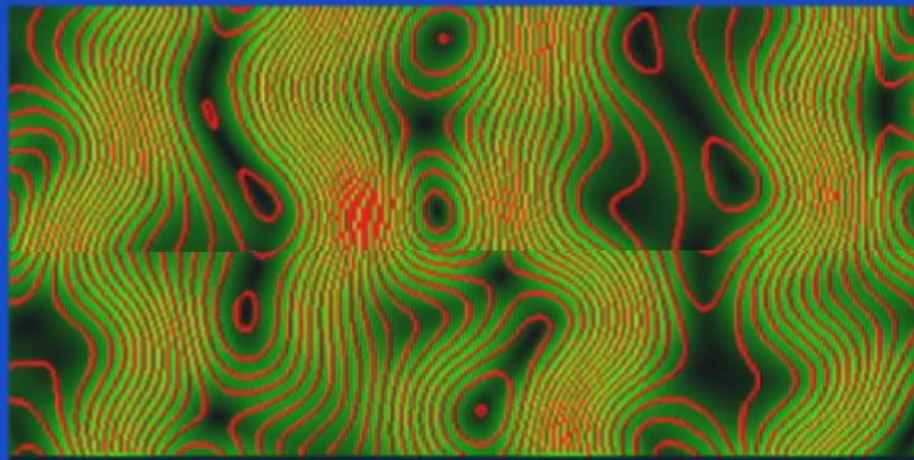
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Density of strings = strength of electric field

Direction of strings = direction of electric field

cpts: $R^a_{bcd} = \Gamma^a_{bd,c} - \Gamma^a_{bc,d}$

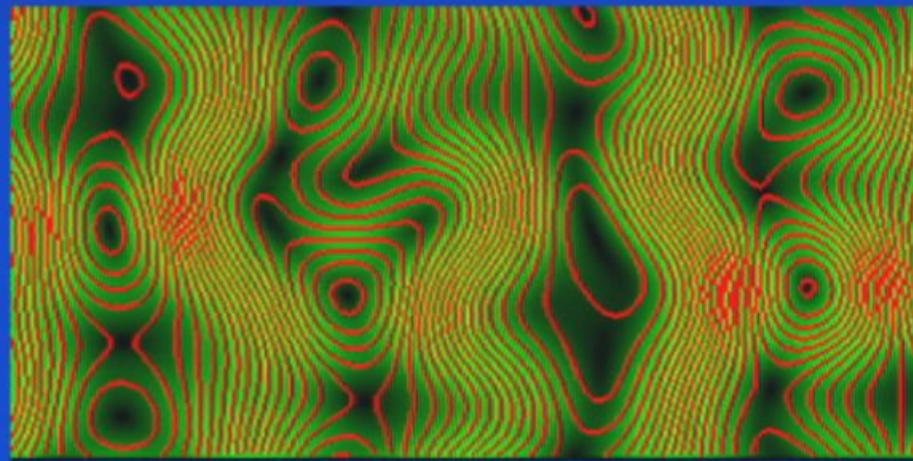
$$\nabla_\mu \vec{\rho} = 0$$

$$+ \Gamma^a_{ce} \Gamma^e_{db} - \Gamma^a_{de} \Gamma^e_{cb} - C^e_{cd} \Gamma^a_{eb}$$

$$\partial_t^2 \rho - v^2 \nabla^2 \rho = 0$$

$$\partial_t^2 u^l - C^l_{ijk} \nabla_i \nabla_j u^k = 0$$

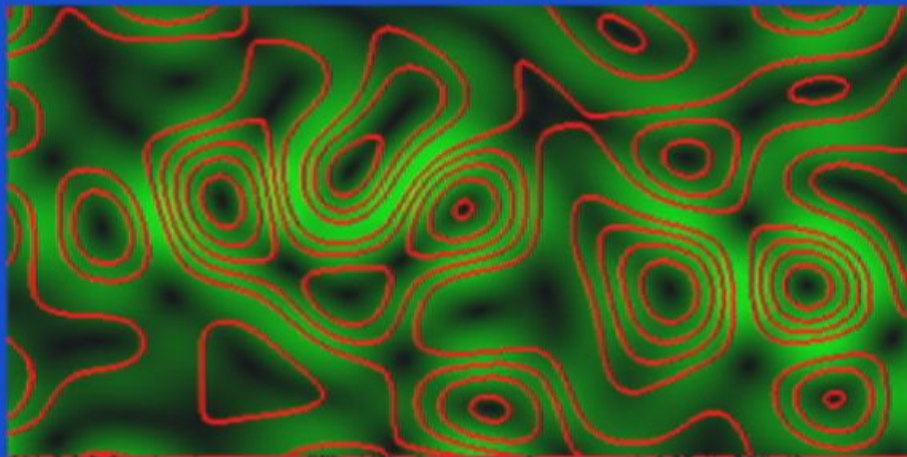
Wave in string liquid = light wave
= electromagnetic wave



Density of strings = strength of electric field

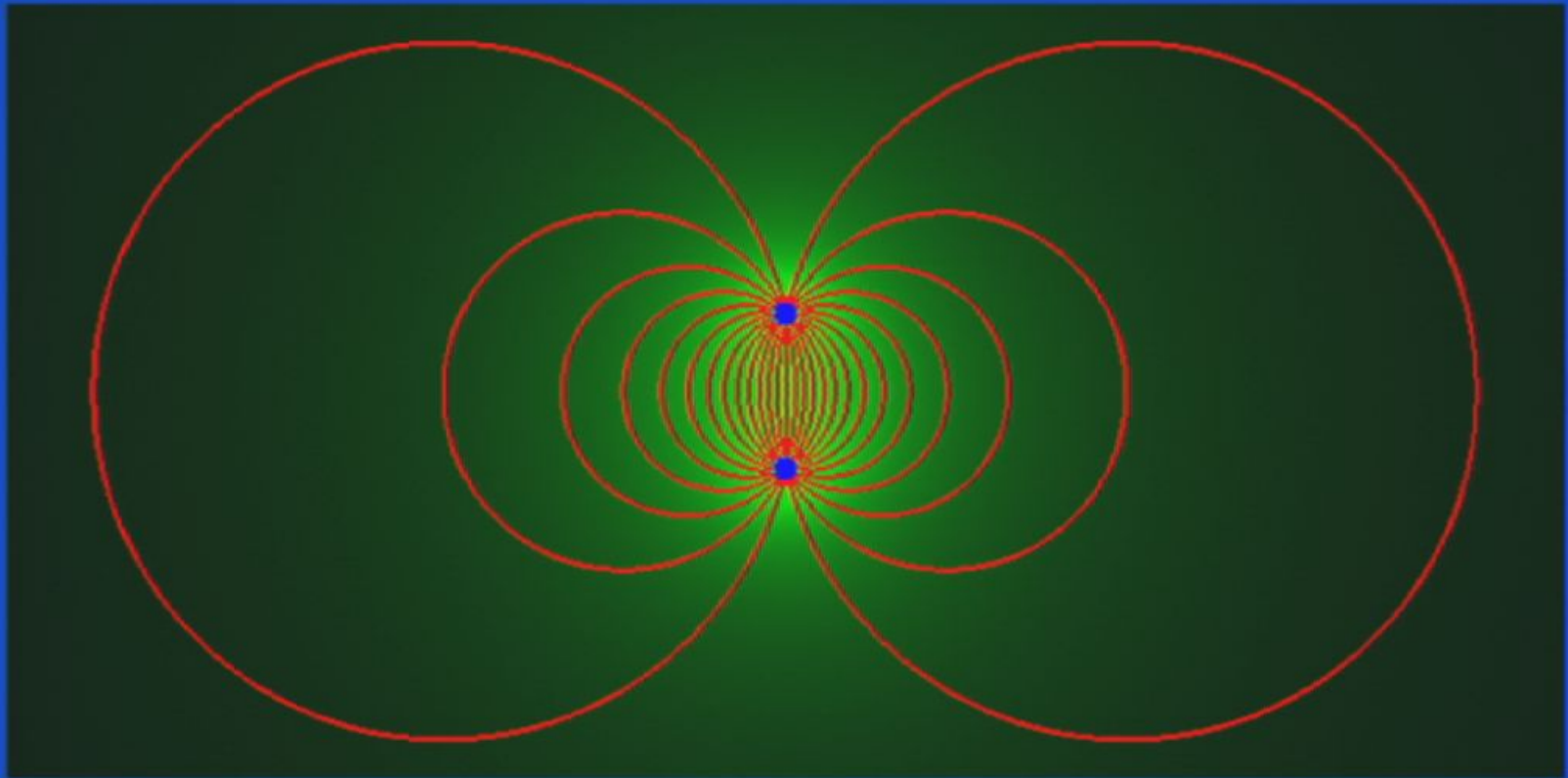
Direction of strings = direction of electric field

String liquid = ether
- the medium that support light wave

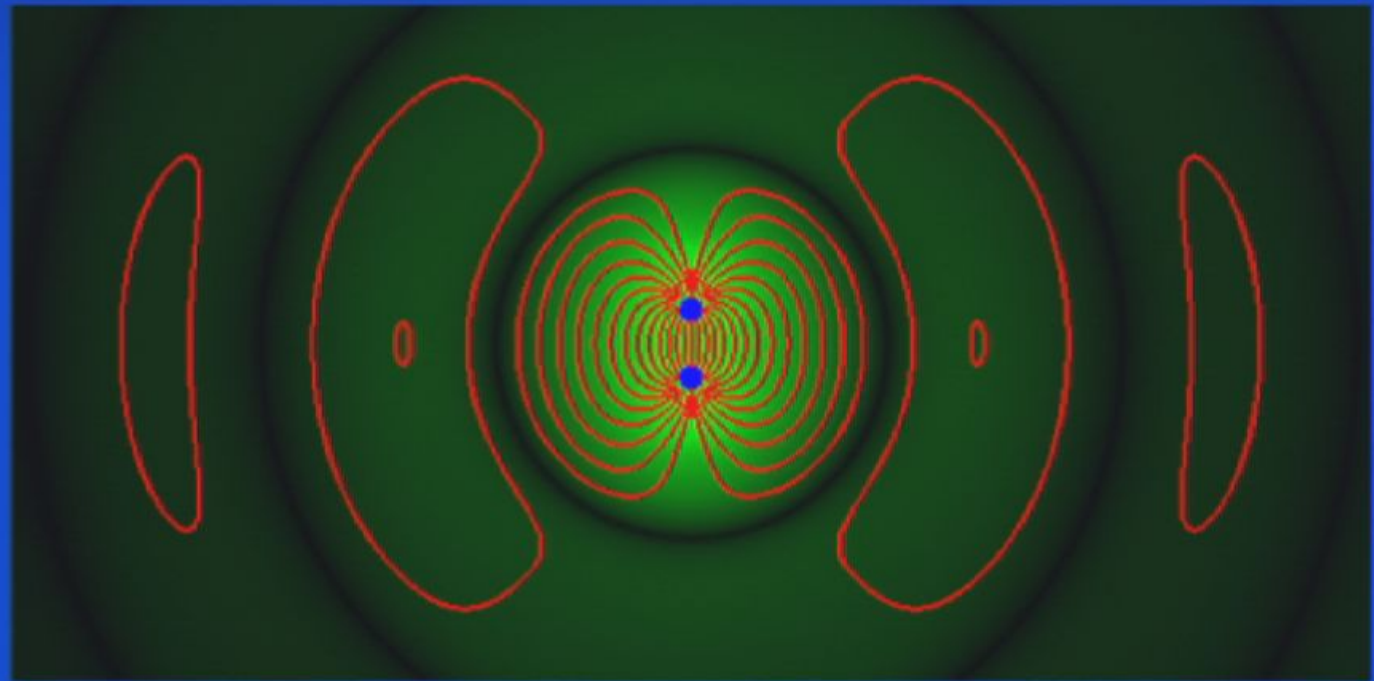
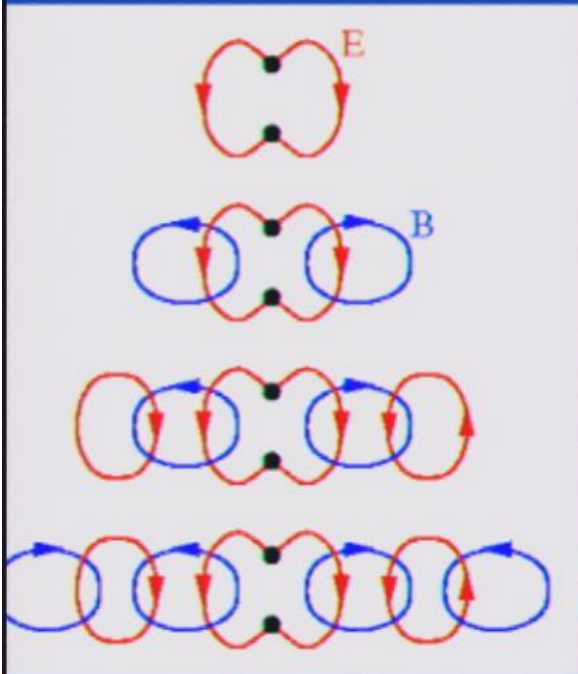


A picture of our vacuum

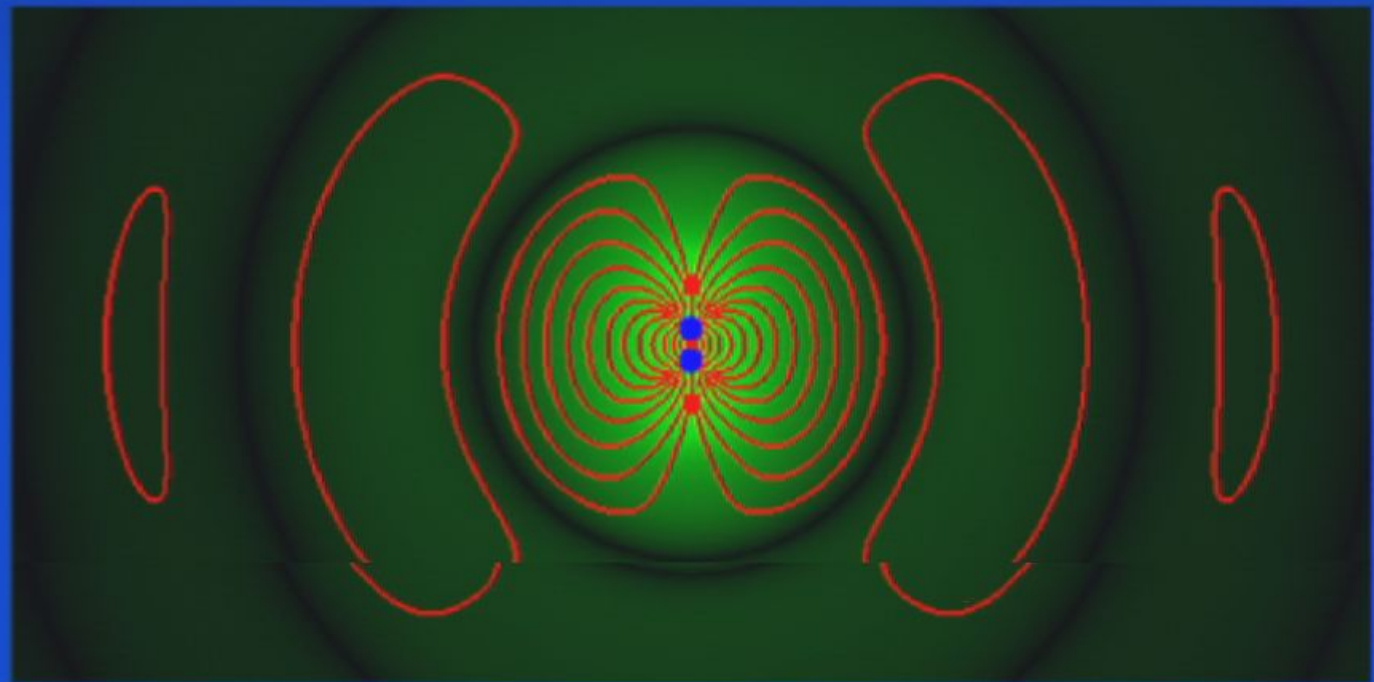
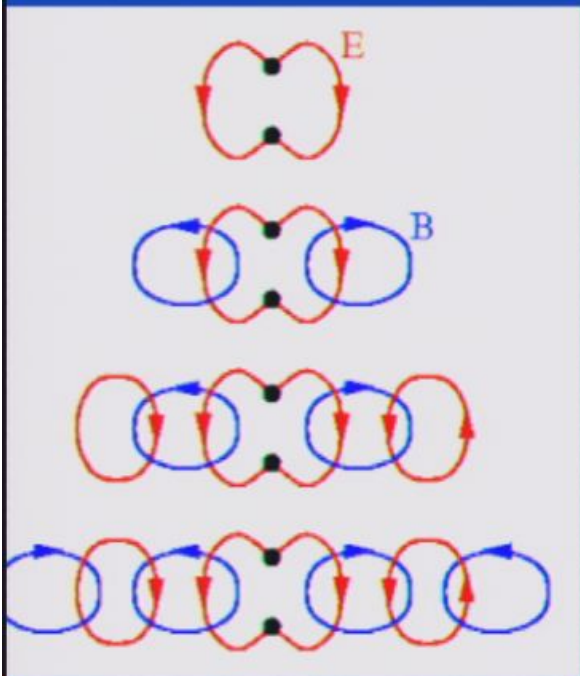
Electric charges = ends of string
= electrons



Vibrating electric charges produce electromagnetic wave (light)

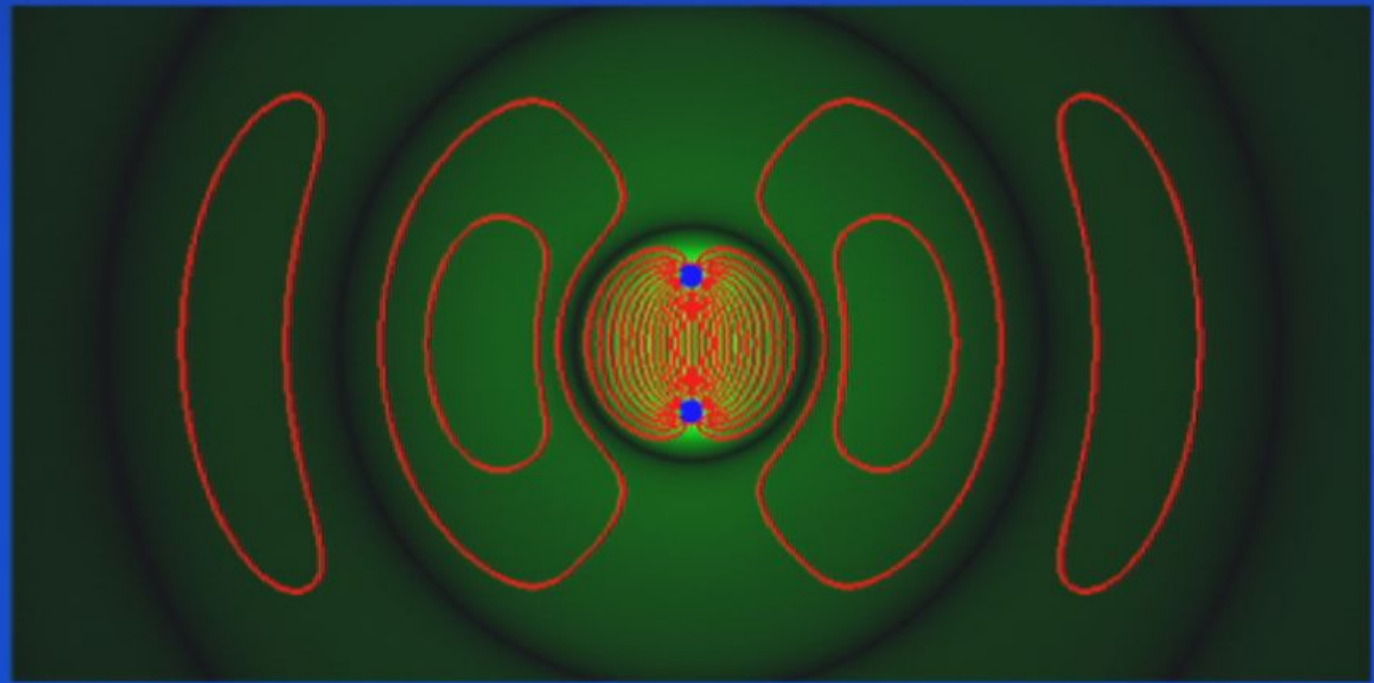
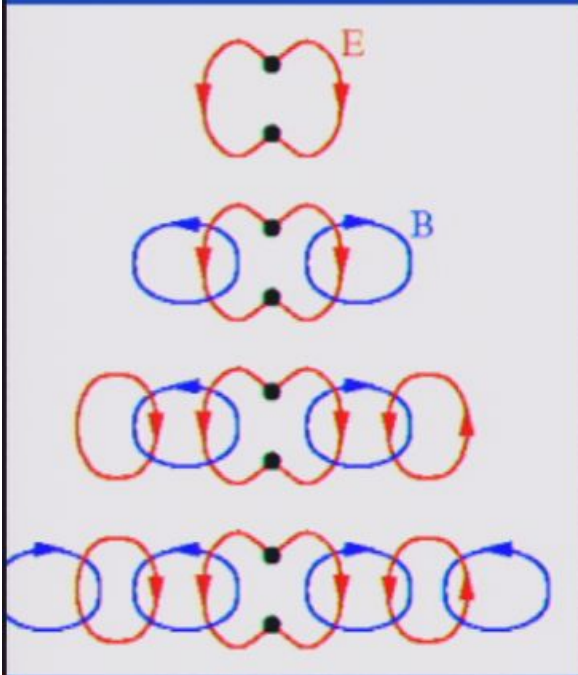


Vibrating electric charges produce electromagnetic wave (light)

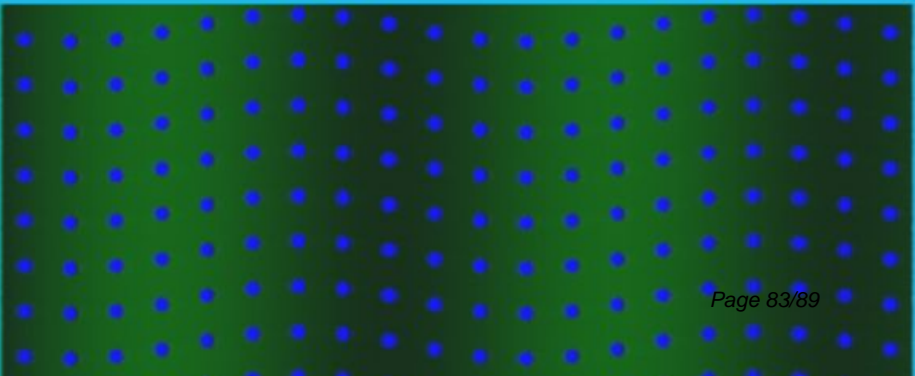
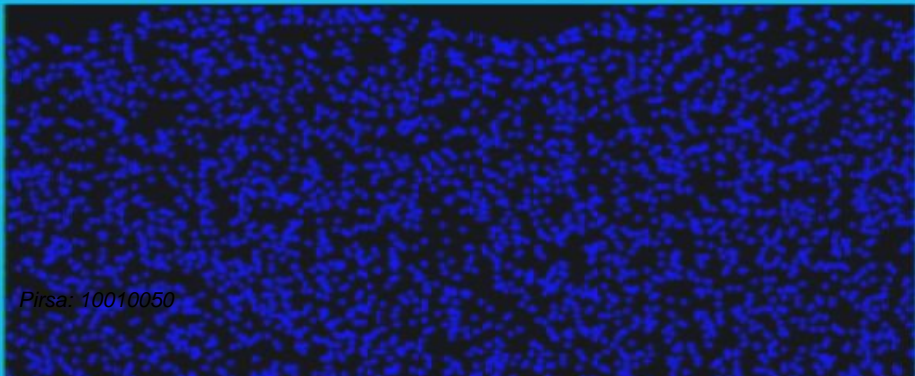
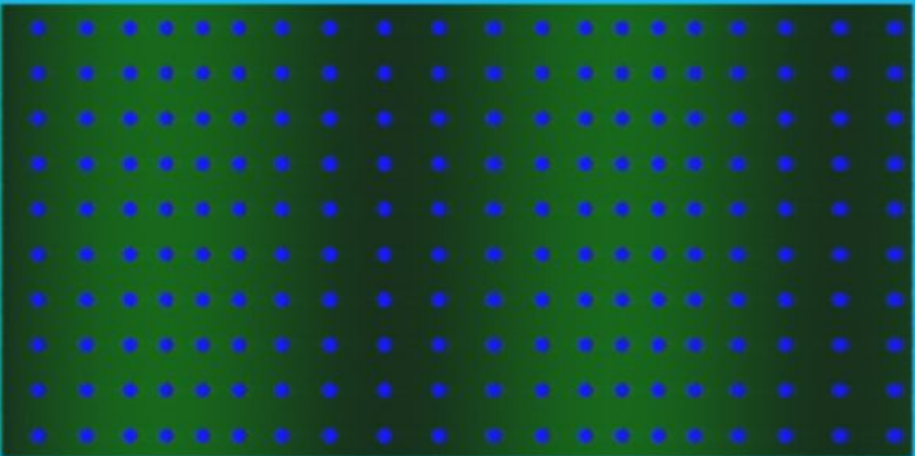
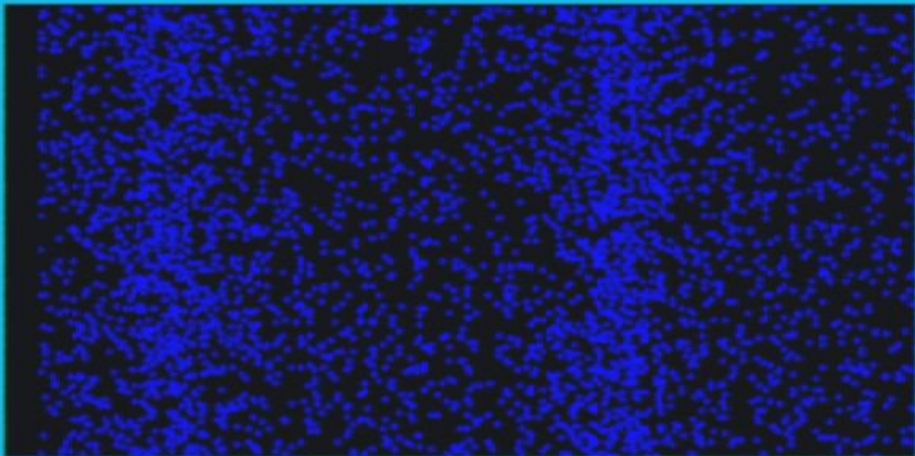
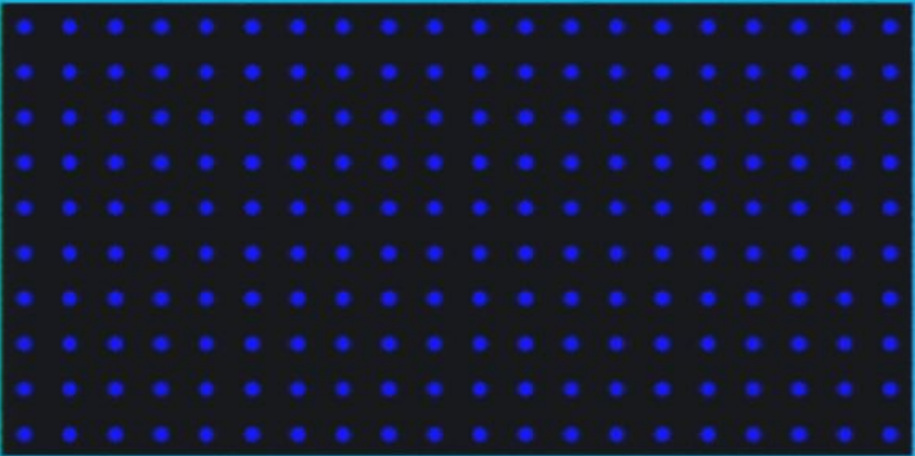
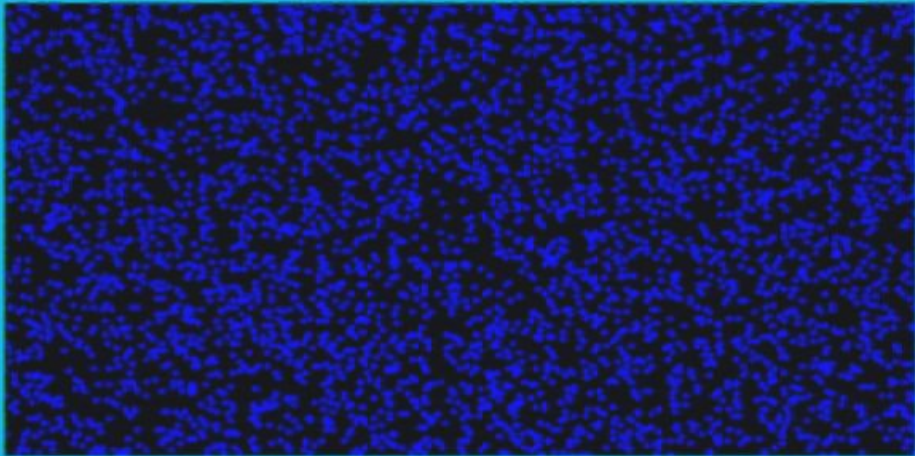


A unification of electrons and light
Electrons = ends of strings

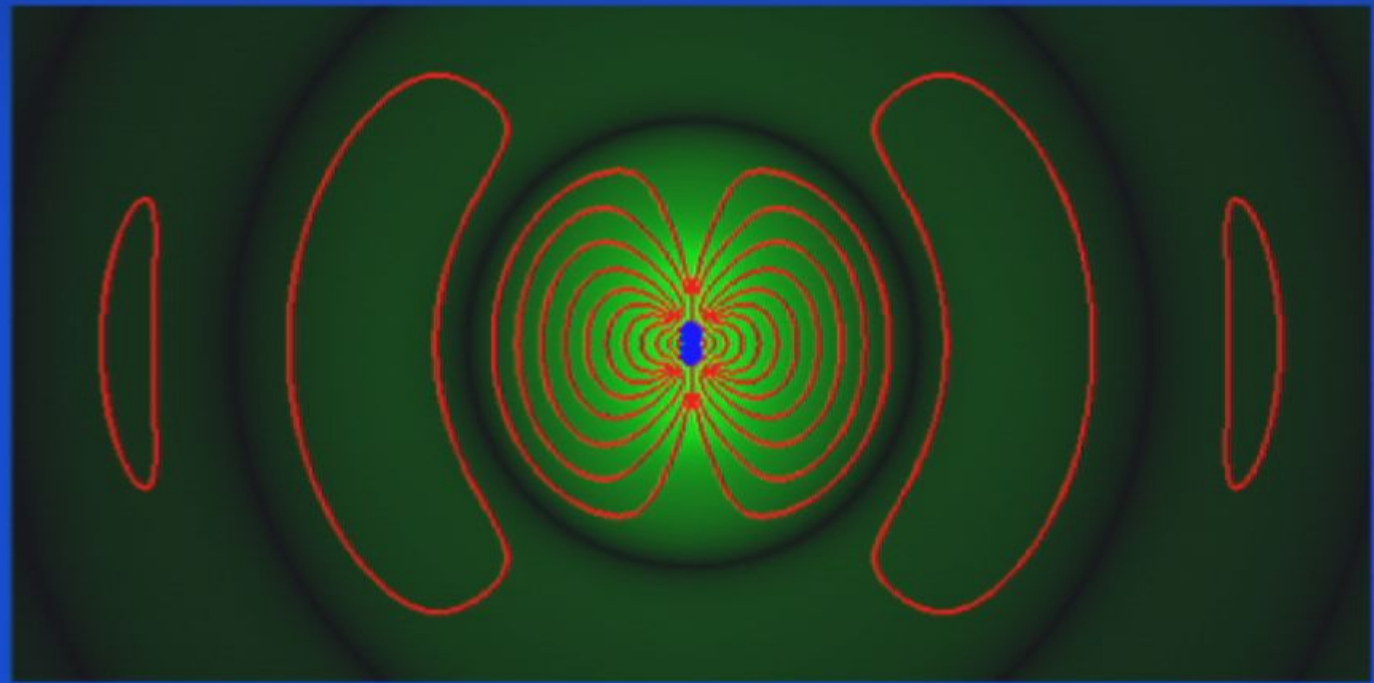
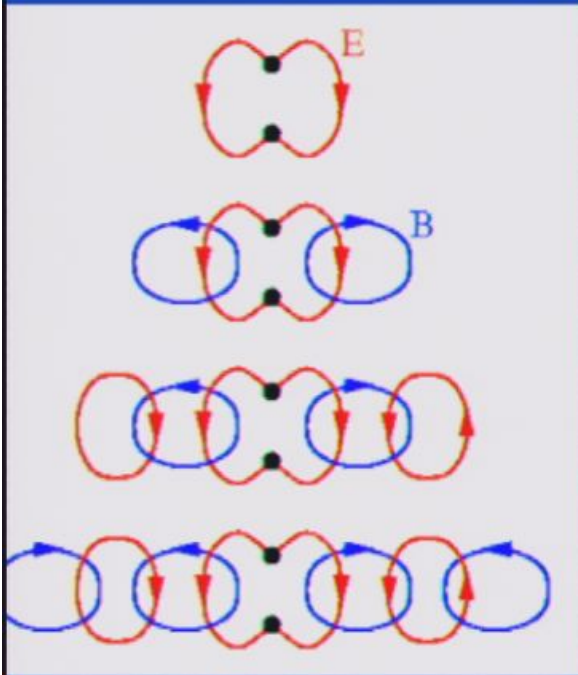
Vibrating electric charges produce electromagnetic wave (light)



A unification of electrons and light
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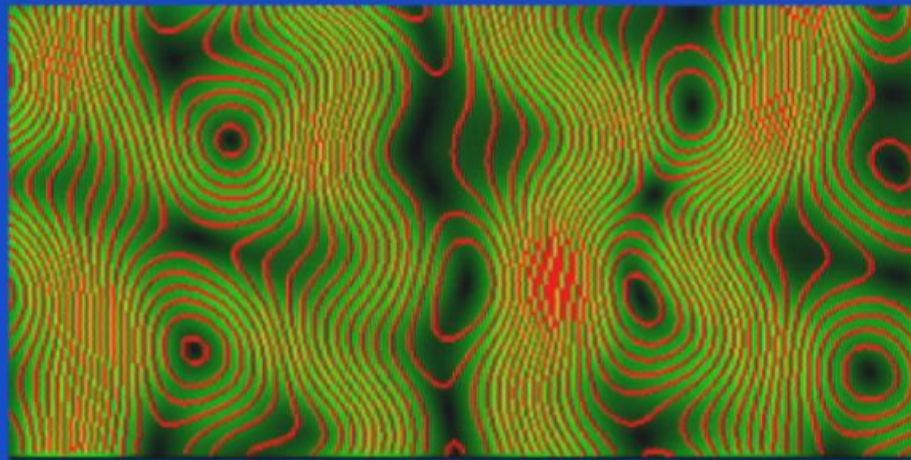


Vibrating electric charges produce electromagnetic wave (light)



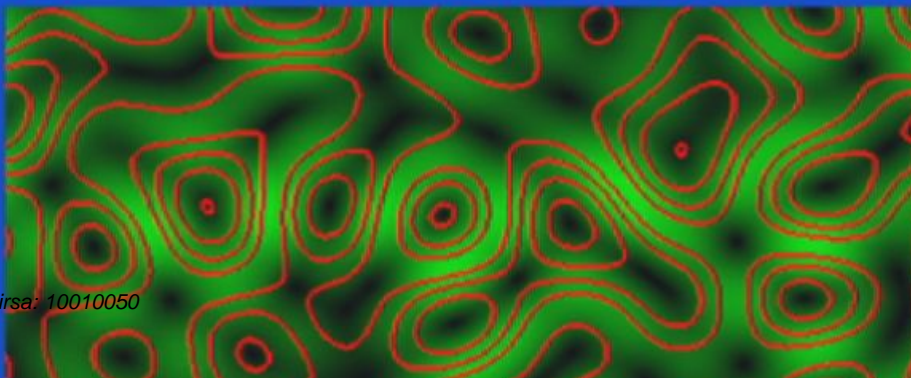
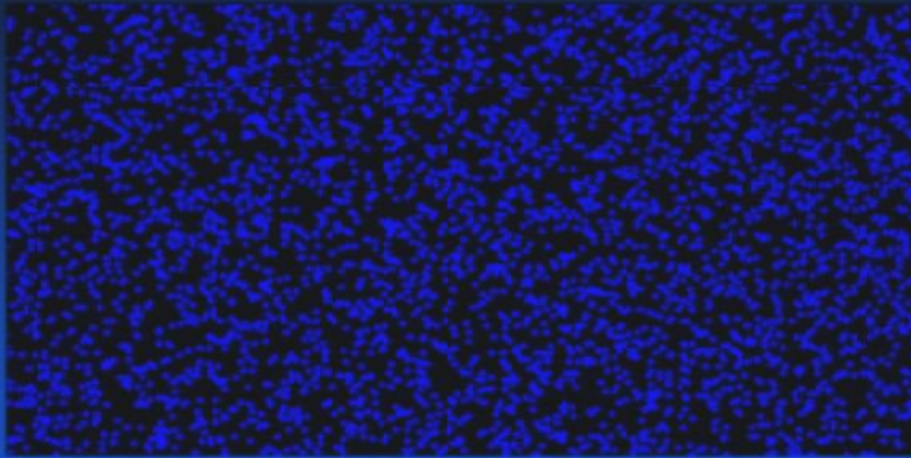
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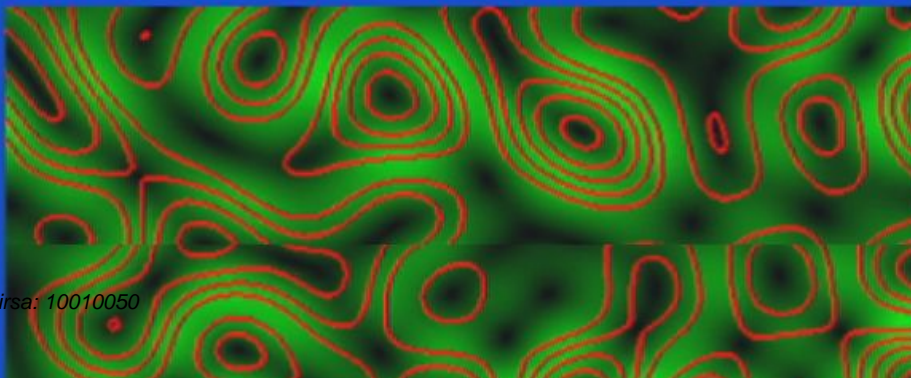
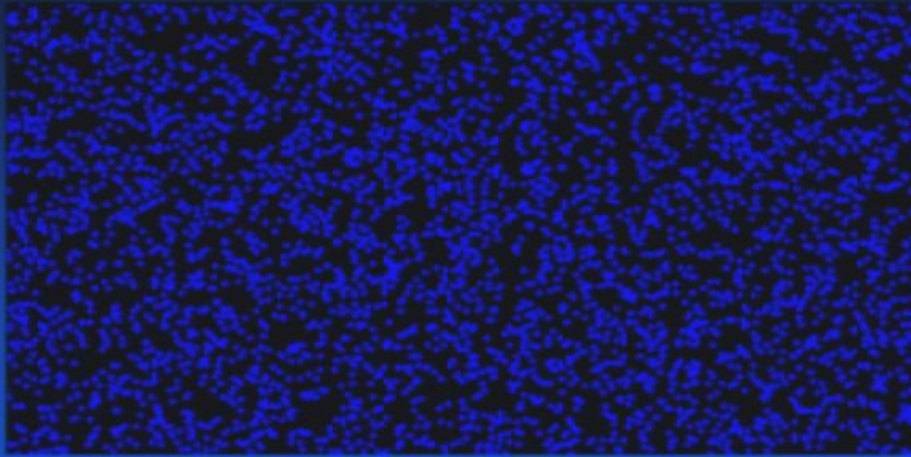
Density of strings = strength of electric field

Direction of strings = direction of electric field



- Three organizations of particles
- Three different universes (vacuums)

We live here,
in a noodle soup
with light



We have materials that realize liquid and crystal

- Can we find a material that realizes string liquid
- Can we hold a model

- **Condensed matter physics studies organizations (orders) of particles and q-bits**
- **The properties of materials are mainly determined from the different orders --- Principle of emergence**
- **Density wave, sound wave, spin wave, mechanical properties, Maxwell equation, Dirac equation, ... can all emerge from certain orders.**

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Order gives us condensed matter

Can order give us everything?