Optics
Polarization

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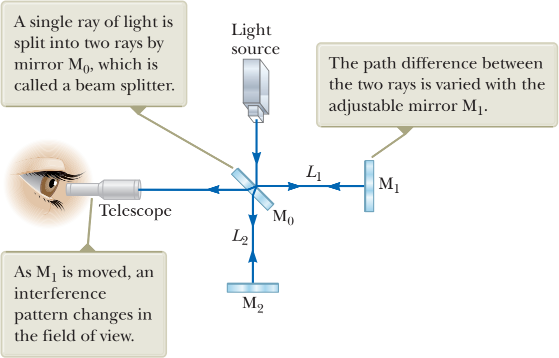
Last time

- interference from thin films
- Newton's rings

Overview

- the interferometer and gravitational waves
- polarization
- birefringence

Michelson Interferometer



Invented by Albert Michelson in 1881, this device featured in two particularly important experiments (and lots more!):

- the Michelson-Morley experiment (1887) – demonstrated there is no ether
- the LIGO experiment (2015) – first experimental detection of gravitational waves

Gravitational Waves

General relativity predicts *gravitational waves*, similar to electromagnetic waves.

However, they are much harder to detect than EM waves!

Massive objects that accelerate (for example, rotation of a non-rotational symmetric object) generate gravitational waves.

Their effect is to distort spacetime as they propagate.

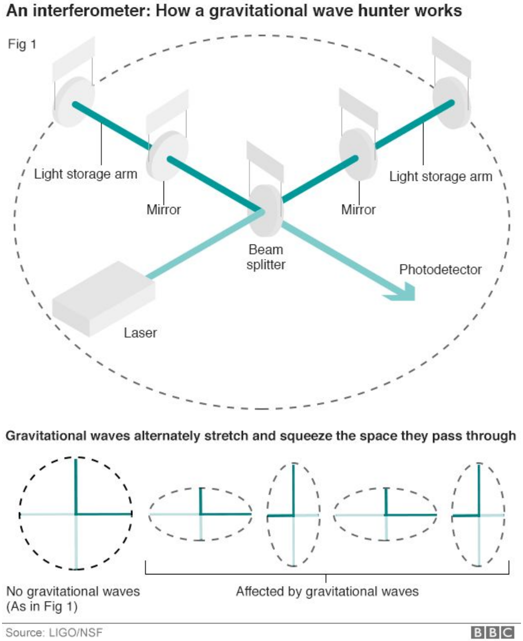
They can tell us about events in the cosmos that we cannot see, and they can travel through matter with almost no scattering.

Laser Interferometer Gravitational-Wave Observatory (LIGO)

Two miles-long interferometers where constructed in Hanford, Washington, and in Livingston, Louisiana.

[1]The LIGO Livingston Observatory in Louisiana. Caltech/MIT/LIGO Lab

Detecting Gravitational Waves



Laser Interferometer Gravitational-Wave Observatory (LIGO)

On Sept 14, 2015, both interferometers observed the same pattern of lengthening and contraction in the arms of their interferometers at basically the same time.

They concluded that the source of the waves was the merger of two black holes.

This was the first confirmed detection of gravitational waves.

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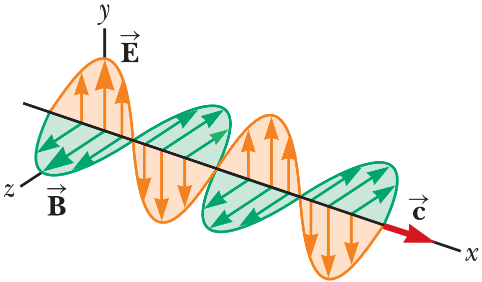
Four black hole collisions have now been observed by LIGO, and one of those also by Virgo, a new interferometer in Italy.

They have also detected a collision of neutron stars (Aug 17, 2017), the first time **both gravitational and EM** waves were seen from the same event. The Fermi gamma ray space telescope detected a coinciding short gamma ray burst.

Polarization

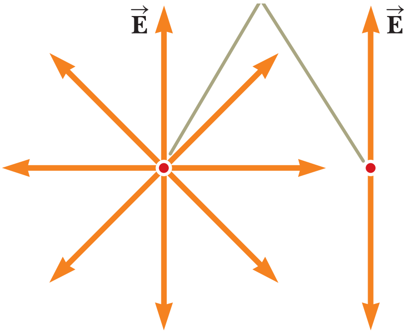
Light is composed of oscillation electric and magnetic fields.



In the diagram the E-field oscillates in the y-direction. The magnetic field must oscillate in perpendicular direction (here x) and the direction of propagation is z.

Polarization

We refer to the direction of oscillation of the E-field as the **polarization direction** of the light ray.



unpolarized light vertically polarized light

Light can also be horizontally polarized or polarized in any other plane.

It can also be **circularly polarized**, meaning the direction of oscillation of the E-field rotates as the ray propagates.

Creating Polarized Light: by Selective Absorption

When unpolarized light of a long wavelength is shone through a set of closely-placed vertical wires, it becomes polarized horizontally.

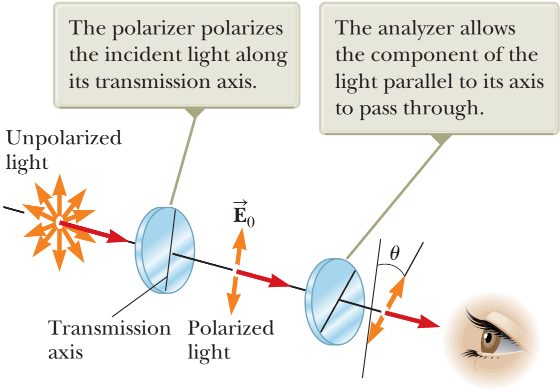
Any light ray with an electric field oscillation that is vertical causes a current in the wires. The energy is absorbed as the electron flow in the wire heats the wire.

The horizontally polarized light has no electric field oscillation vertically, so it passes through the wires without interacting with them.

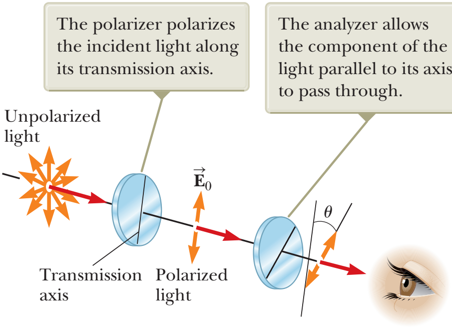
Creating Polarized Light: by Selective Absorption

For shorter wavelengths a material called *polariod* will do the same thing.

It is composed of long-chain hydrocarbons that have been treated to become better conductors.



Dependence of Intensity on Angle of the Polarizers



When the analyzer is at an angle θ with respect to the transmission axis of the polarizer, the intensity of light transmitted through both is:

$$I = I_{\max} \cos^2 \theta$$

where $I_{\max}$ is the intensity of the light after the first polarizer. This is called **Malus's law**.

Question

Quick Quiz 38.6[1] A polarizer for microwaves can be made as a grid of parallel metal wires approximately 1 cm apart. Is the electric field vector for microwaves transmitted through this polarizer

(A) parallel

(B) perpendicular

to the metal wires?

[1]Serway & Jewett, page 1181.

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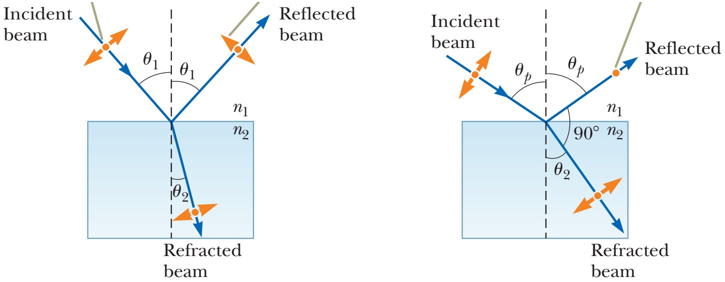
Creating Polarized Light: by Reflection

When light strikes a smooth surface of a transparent material, some light is reflected and some is transmitted.

Interestingly, the polarization of the transmitted beam is not the same as of the reflected beam!

If the incident ray is unpolarized, the transmitted and reflected rays will be partially polarized.

Creating Polarized Light: by Reflection

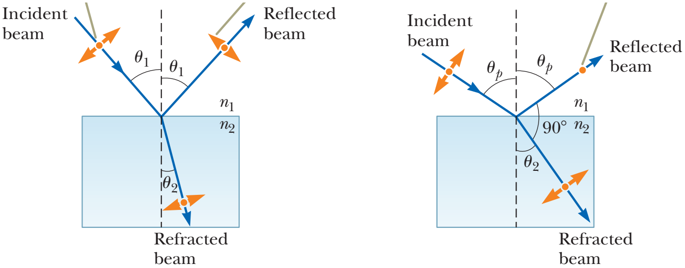


The dipoles in the surface cannot create a ray that has an E-field oscillating in the direction that the ray travels.

When the reflected and refracted rays are perpendicular, the reflected ray is completely polarized parallel to the surface.

Creating Polarized Light: by Reflection

The value of the incident angle for the reflected and transmitted rays to be perpendicular, θ_p is called **Brewster's angle**.



Notice, $\theta_2 = 90° - \theta_p$. From Snell's Law:

$$\begin{aligned} n_1 \sin\theta_p &= n_2 \sin(90° - \theta_p) \\ n_1 \sin\theta_p &= n_2 \cos(\theta_p) \end{aligned}$$

So,

$$\theta_p = \tan^{-1}\left(\frac{n_2}{n_1}\right)$$

Summary

- the interferometer
- polarization

Final Exam 9:15-11:15am, Tuesday, June 26.

Homework Serway & Jewett:

- prev: Ch 37, onward from page 1150. OQs: 1, 5, 7; Probs: 43, 54, 63, 68
- new: Ch 38, onward from page 1182. OQs: 1, 7; Probs: 45, 49, 51, 63, 65, 70