Optics
Interference from Films
Newton's Rings
Michelson Interferometer

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Last time

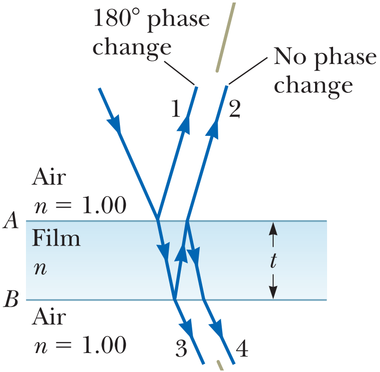
- diffraction patterns
- diffraction and interference
- resolution and Raleigh's criterion
- reflection and phase changes

Overview

- interference from thin films
- Newton's rings
- the interferometer
- polarization
- birefringence

Thin Film Interference

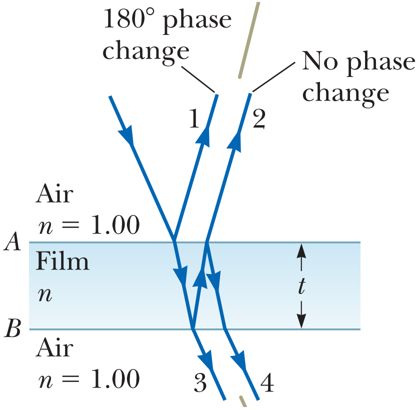
Consider a film of liquid (or solid) with refractive index n.



Imagine the incident ray shines **directly down into the surface**.

We draw it making a small angle to the vertical so that we can clearly see the reflections.

Thin Film Interference



Ray 1 undergoes a 180° (*ie.* $\lambda/2$) phase shift at boundary A.

Ray 2 travels an extra distance of $2t$ and has a phase shift of 0° at boundary B.

Thin Film Interference

The condition for **constructive interference** between rays 1 and 2 is:

$$2t = \left(m + \frac{1}{2}\right)\lambda_n \qquad m \in \mathbb{Z}$$

where $\lambda_n = \frac{\lambda}{n}$ is the wavelength of the light in the film. We can rewrite this as:

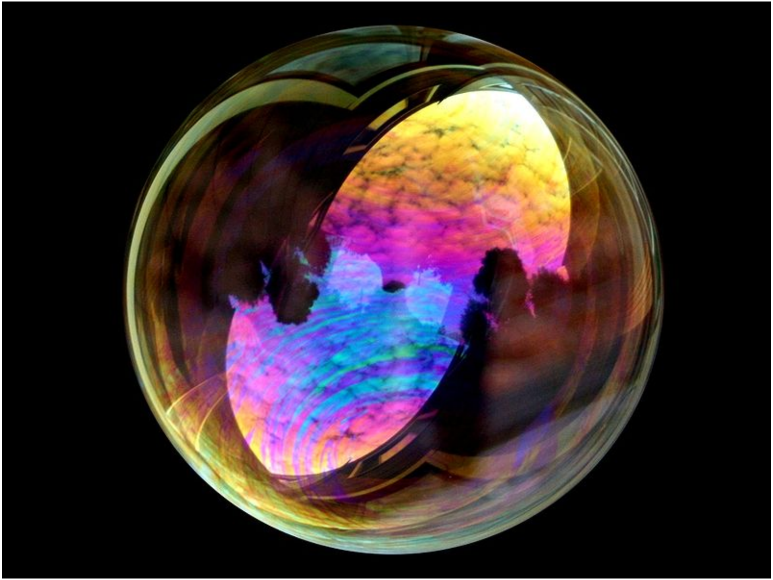
$$2nt = \left(m + \frac{1}{2}\right)\lambda \qquad m \in \mathbb{Z}$$

For destructive interference:

$$2nt = m\lambda \qquad m \in \mathbb{Z}$$

These expressions depend on the choice of media: if there is something other than air below or above the film the conditions will change.

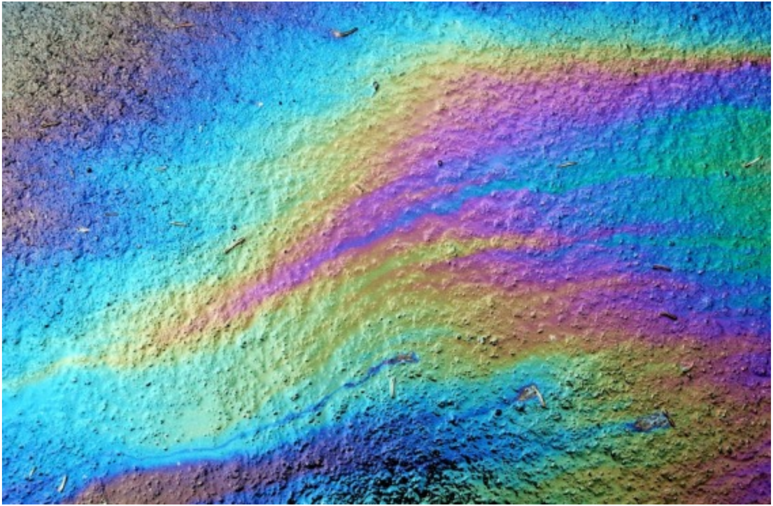
Thin Film Interference



[1] From Dr. Chris L. Davis's page, http://www.physics.louisville.edu/cldavis/

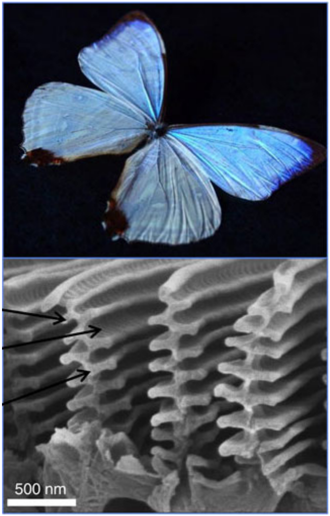
Thin Film Interference

Oil floating on water on pavement after rain.



Iridescence in Biology

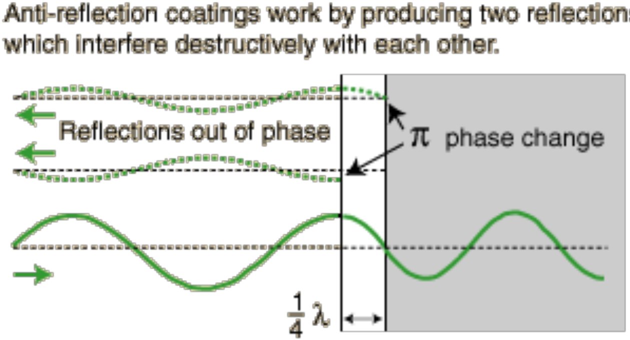
Iridescence in Biology



[1]Left photo by Didier Descouens; right Radislav A. Potyrailo et al. Nature Communications 6: 7959, 2015.

Antireflective Coatings

Antirelective coatings are used on eyeglasses and camera lenses to cut down on glare and increase the transmitted light.



[1] http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

Interference by reflection question

Quick Quiz 37.3[1] One microscope slide is placed on top of another with their left edges in contact and a human hair under the right edge of the upper slide. As a result, a wedge of air exists between the slides. An interference pattern results when monochromatic light is incident on the wedge. What is at the left edges of the slides?

(A) a dark fringe

(B) a bright fringe

(C) impossible to determine

[1] Serway & Jewett, page 1144.

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Newton's Rings

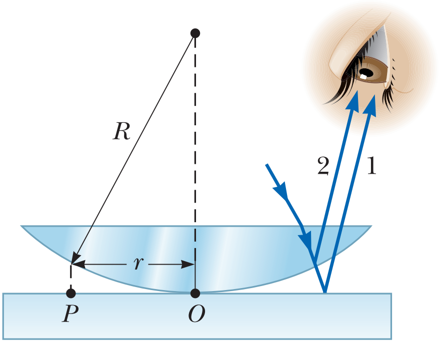
Newton's rings are another independence pattern, formed when a plano-convex lens rests on a flat surface that can reflect light.

They are named for Isaac Newton who studied them after their discovery by Robert Hooke.

They were used to assess the quality of lenses.

Newton's Rings

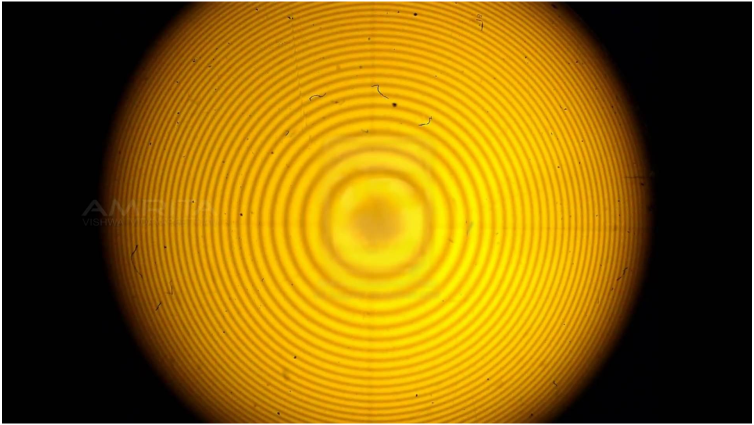
Light shines from above into the lens and is reflected both from the bottom of the lens and the flat glass plate below. These two rays interfere.



[1]Figure from Serway & Jewett.

Newton's Rings

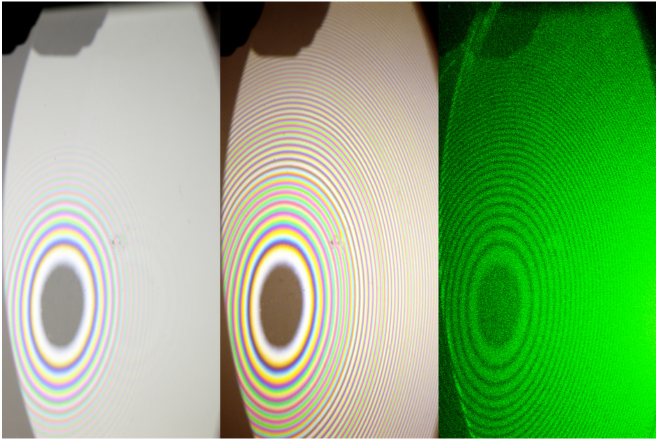
Interference pattern produced with monochromatic light.



[1]Photo from Amrita University Vlab.

Newton's Rings

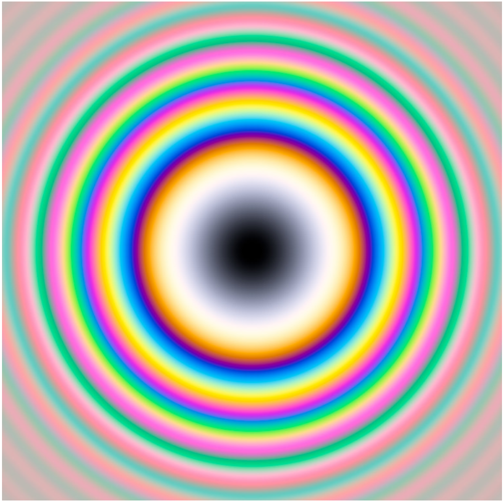
Interference patterns produced with broad-spectrum light (left), mercury fluorescent (limited spectrum), and monochromatic laser light.



[1] Photo by Bob Fosbury.

Newton's Rings

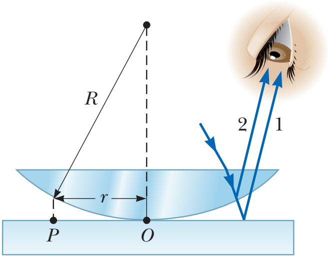
Computer model of Newton's rings for full visible spectrum illumination.



[1]From the Scientific Legal Tourist blog.

Newton's Rings

The **dark rings** for a particular wavelength can be found using the same ideas as for the thin film.



$$\text{dark:} \quad 2nt = m\lambda \qquad \text{(lens in air so } n = 1\text{)}$$

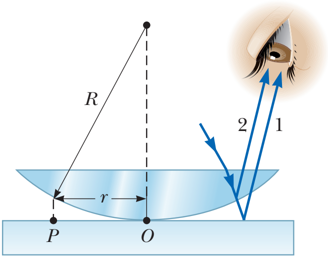
here, t is the depth of the air gap.

$$t = R - \sqrt{R^2 - r^2}$$

Assuming $r \ll R$, we can use a Taylor expansion about $r = 0$ to show:

$$t \approx \frac{r^2}{2R}$$

Newton's Rings



$$2nt = m\lambda \quad ; \qquad t \approx \frac{r^2}{2R}$$

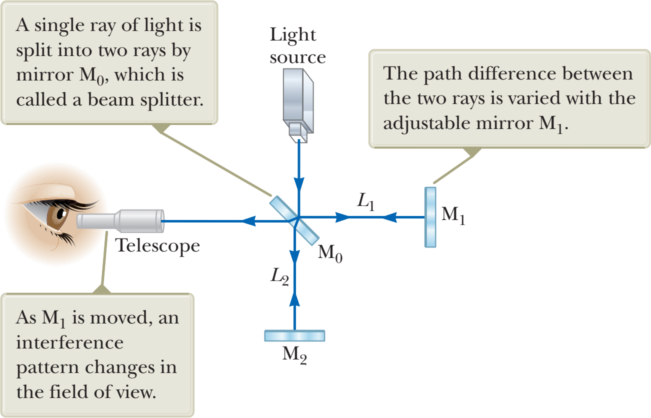
Using the expression for t and rearranging, we see that dark rings occur at radii:

$$r = \sqrt{\frac{m\lambda R}{n}}$$

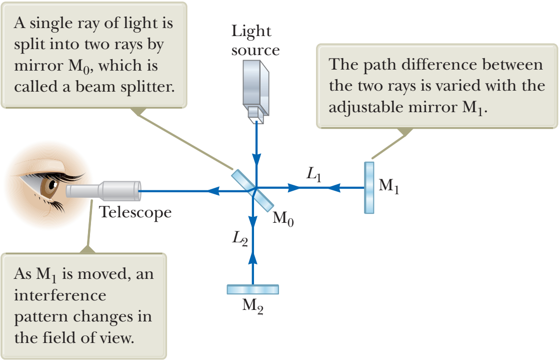
where $n = 1$ if the lens is surrounded by air.

Michelson Interferometer

The Michelson interferometer is an ingenious device for studying interference, measuring wavelength, measuring path differences, finding optical thicknesses of various optical components, studying quantum effects, and spectroscopy (determining a spectrum from a source).



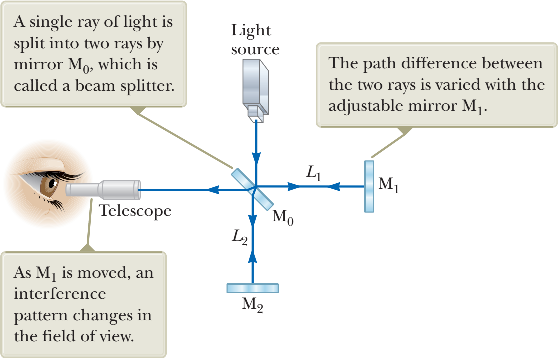
Michelson Interferometer



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

Michelson Interferometer



- M_0 is a "half-silvered mirror" called a *beamplitter*. It transmits half the light that strikes it and reflects the rest.
- M_1 is a movable mirror. Using a screw mechanism you can very slowly move it closer to or further from M_0.
- M_2 is a fixed mirror.
- The telescope is used to view the interference pattern that forms.

Michelson Interferometer

The interference effects occur because the two paths for the light can be made different lengths.

Let the source be S and the telescope be T.

Path 1: $S \to M_0 \to M_1 \to M_0 \to T$

Path 2: $S \to M_0 \to M_2 \to M_0 \to T$

The only part that differs is the arm traveled to the mirror M_1 or M_2, so the path difference is

$$\delta = |2L_1 - 2L_2|$$

Michelson Interferometer

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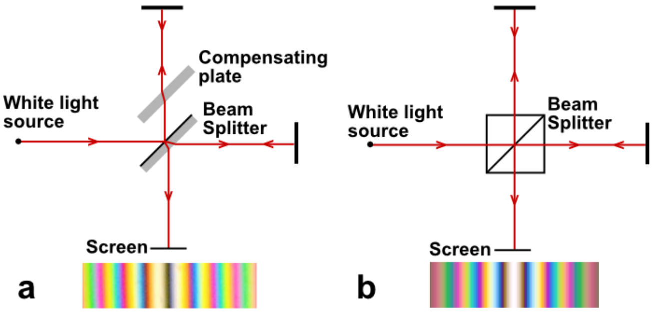
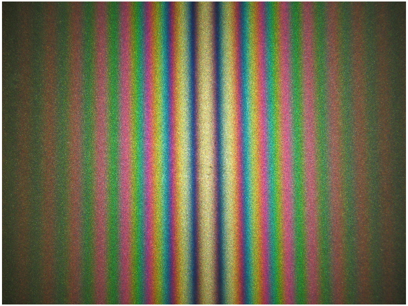
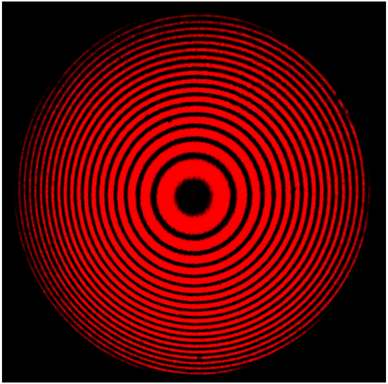
The condition for the $\delta = 0$ fringe to be bright or dark depends on the details of the experimental arrangement (*eg.* beamsplitter designs and coatings).



Michelson Interferometer Interference Patterns



white light, tilted mirrors,
cube beamsplitter, $\delta = 0$



monochromatic light,
point source

[1] Left photo by Alain Le Rille; right Univ. of Toronto Physics Dept

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.

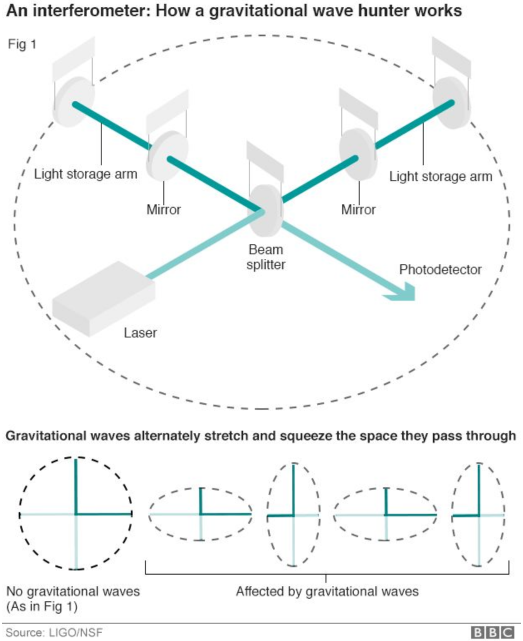
They can tell us about events in the cosmos that we cannot see, and they can travel through matter with almost no scattering.

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.

Summary

- interference from thin films
- Newton's rings
- the interferometer

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

Homework Serway & Jewett:

- prev: Ch 37, onward from page 1150. OQs: 5, 7; Probs: 35, 61, 67, (31, 37, 40 covered today)
- new: Ch 37, onward from page 1150. OQs: 1, 5, 7; Probs: 43, 54, 63, 65, 68