# Holography & Coherence

- For Holography need coherent beams
- Two waves coherent if fixed phase relationship between them for some period of time

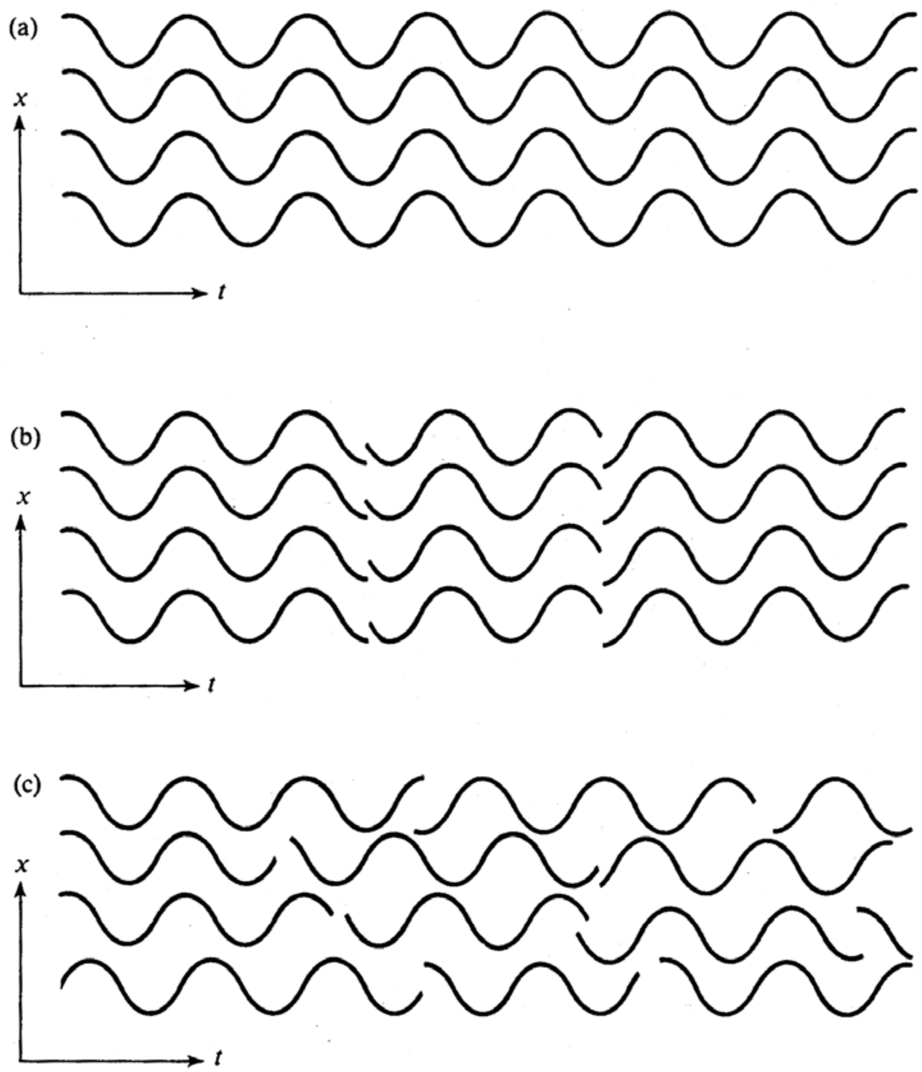



**Fig. 3.8** An illustration of coherence. In (a) we show a perfectly coherent beam. All the constituent waves are in phase at all times. In (b) we have a beam which is spatially coherent, but which exhibits only partial temporal coherence. This is because the waves simultaneously change their phases by an identical amount every few oscillations. In (c) we show an almost completely incoherent beam where the phases of each wave change randomly at random times. Note however that even in this case some small degree of temporal coherence remains, since over very short time intervals the phases are to some extent predictable.

# Coherence

• Coherence appear in two ways

**Spatial Coherence**

• Waves in phase in time,
  but at different points in space

• Required for interference and diffraction

• Before lasers need to place slits far from source
  or pass light through slit so only part of source seen

**Temporal Coherence**

• Correlation of phase at the same point
  but at different times

• Regular sources rapidly change phase relationships

• Single atom on $10^{-8}$ sec coherent
  lifetime of atom in an excited state

• Much shorter for groups of atoms

• For lasers in single mode much longer time

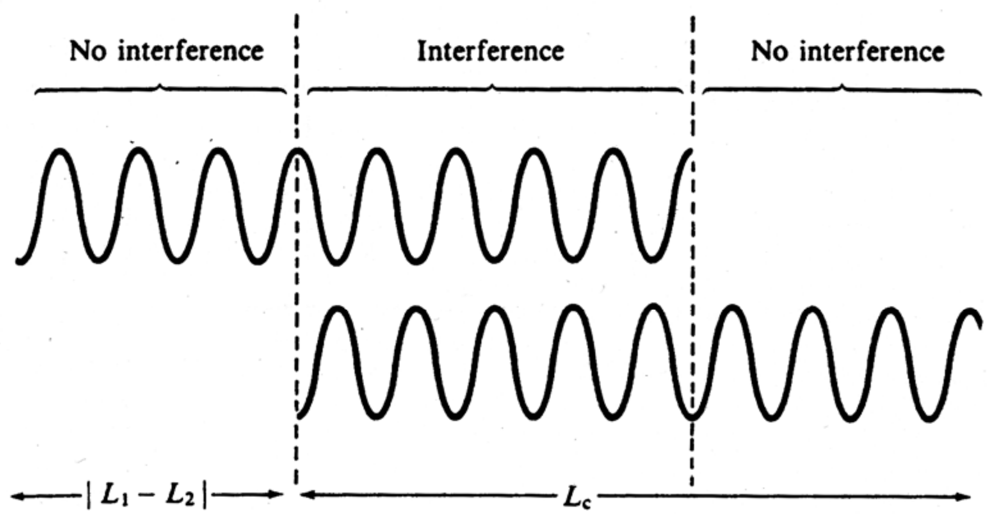



Fig. 3.10 When two identical wavetrains of length $L_c$ which have traveled different distances ($L_1$ and $L_2$) are recombined they can only interfere over a length $L_c - |L_1 - L_2|$.

# Coherence Length and Time

- Time of coherence given by $\tau_{coh}$
- Coherence time about time taken for photon to pass a given distance (Coherence length) in space
- Coherence length is

$$L_{coh} = c\tau_{coh}$$

- Best seen in Michelson-Morley experiment
- Beam is split into two beam paths, reflected and combine
- If get interference pattern then within Coherence lengths
- Before lasers paths needed to be nearly equal
- With lasers only require

$$2(L_1 - L_2) < L_{coh}$$

- Coherence last 50 - 100 m with lasers

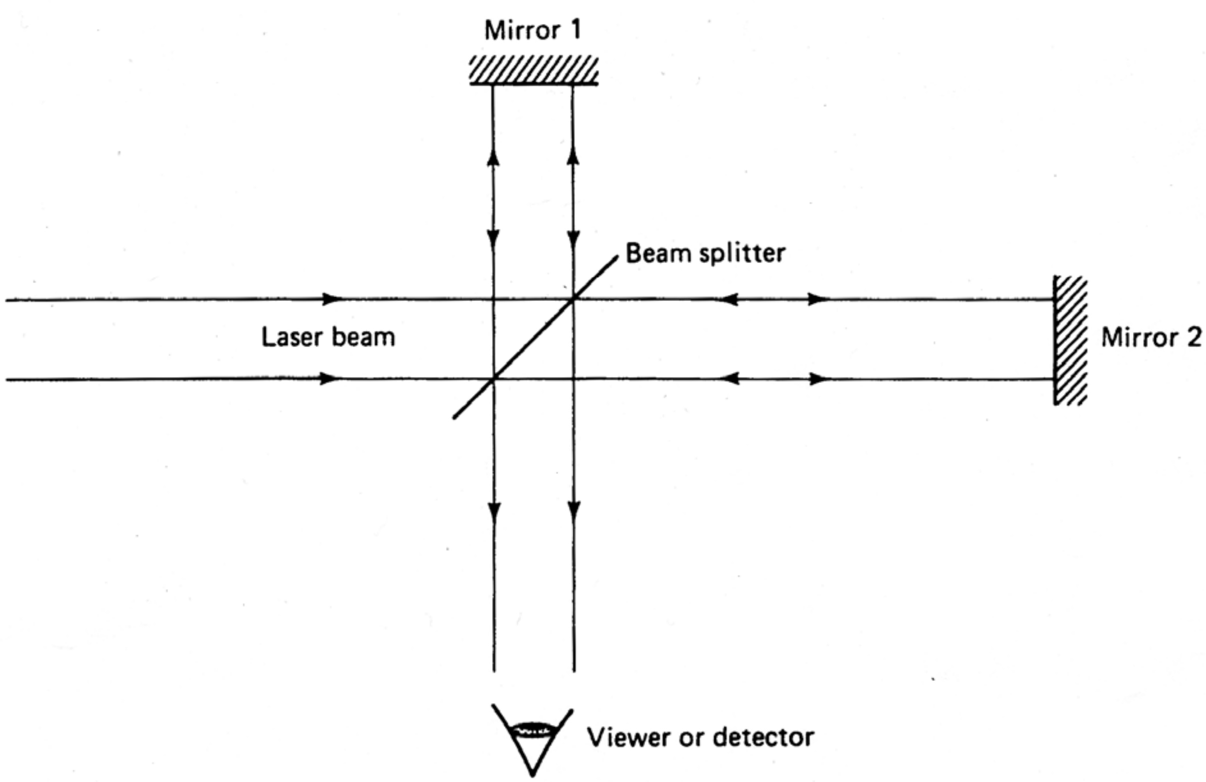



**Figure 1-24** Michelson interferometer.

# Coherence Length and Lasers

- It can be shown Coherence time related to
  laser frequency width Δν (linewidth)

$$\tau_{coh} = \frac{1}{\Delta\nu}$$

- As the coherence length is

$$L_{coh} = c\,\tau_{coh}$$

- For holography setup distances must be < coherence length
- Long coherence lasers have small linewidth, thus high stability

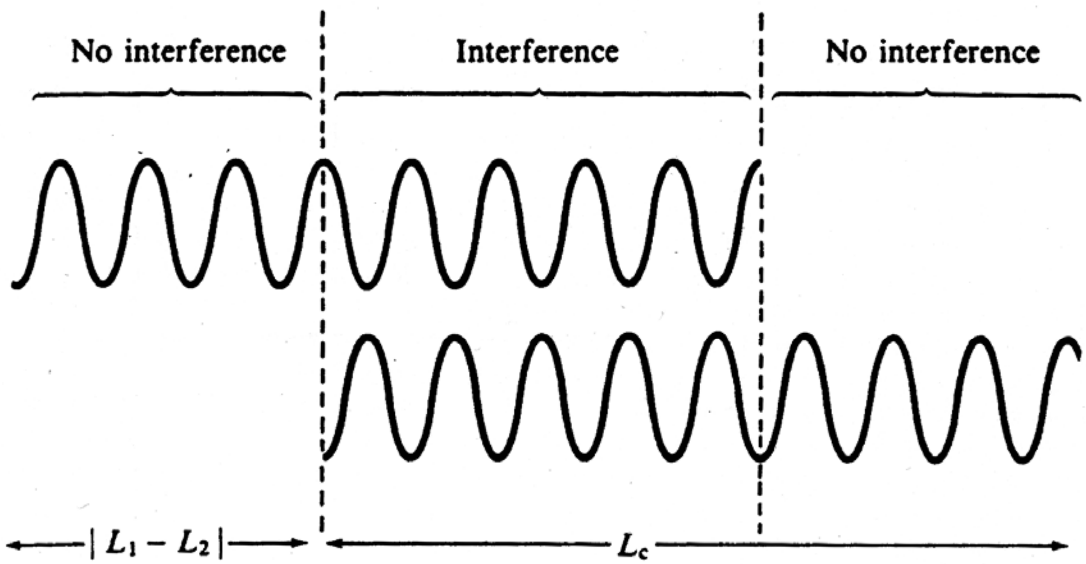



**Fig. 3.10** When two identical wavetrains of length $L_c$ which have traveled different distances ($L_1$ and $L_2$) are recombined they can only interfere over a length $L_c - |L_1 - L_2|$.

# Example of Coherence Length

**Sodium vapour lamp yellow "D" line**

- $\lambda$ = 589 nm and linewidth 5.1x10$^{11}$ Hz
- Thus coherence time and length is

$$\tau_{coh} = \frac{1}{\Delta\nu} = \frac{1}{5.1x10^{11}} = 1.96\,x10^{-12}\ sec$$

$$L_{coh} = c\,\tau_{coh} = 2.98x10^{8}\left(1.96\,x10^{-12}\right) = 5.88x10^{-4}\,m = 0.59mm$$

- Coherence small hence hard to create holograms

- HeNe laser in multimode operation
- $\lambda$ = 632.8 nm and linewidth 1500 MHz
- Thus coherence time and length is

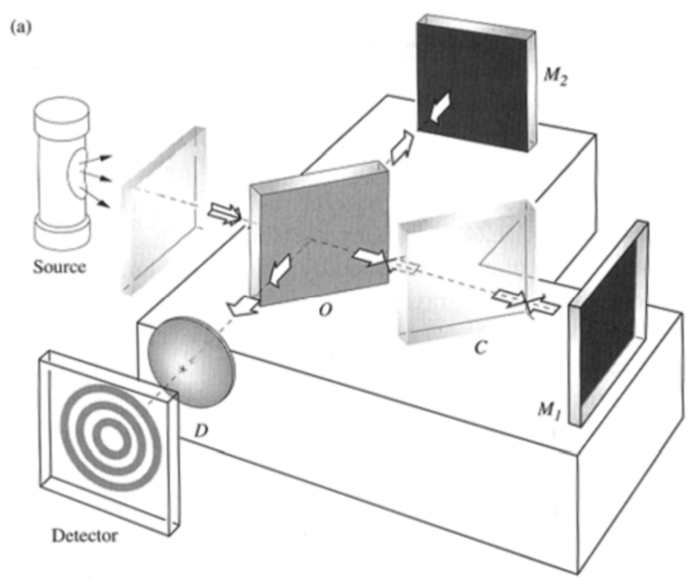
$$\tau_{coh} = \frac{1}{\Delta\nu} = \frac{1}{1.5x10^{9}} = 6.67\,x10^{-10}\ sec$$

$$L_{coh} = c\,\tau_{coh} = 2.98x10^{8}\left(6.67\,x10^{-10}\right) = 0.2\ m$$

- If single mode HeNe operation linewidth goes to 1 Mz and cohrence time is 1 microsec, cohrence length 300 m

# Interferometers

- Can use interference effects to precisely measure distance
- First example Michelson Interferometer
- Have 2 mirrors ($M_1$ & $M_2$) placed on arms at 90 degrees
- Splitting mirror O (half silvered mirror) at intersection
- Splitter mirror – reflects part (~50%) of light $90^o$
  Lets part pass directly through
- Of a thin film of Aluminium ~100 nm, not full absorbing
- Monochormatic & coherent light source along path of one arm
- Detector at other arm
- Light to $M_1$ is reduced, reflected by $M_1$ then by splitter to detector
- Light at splitter reduced but reflected to $M_2$
- The passed through splitter O to detector



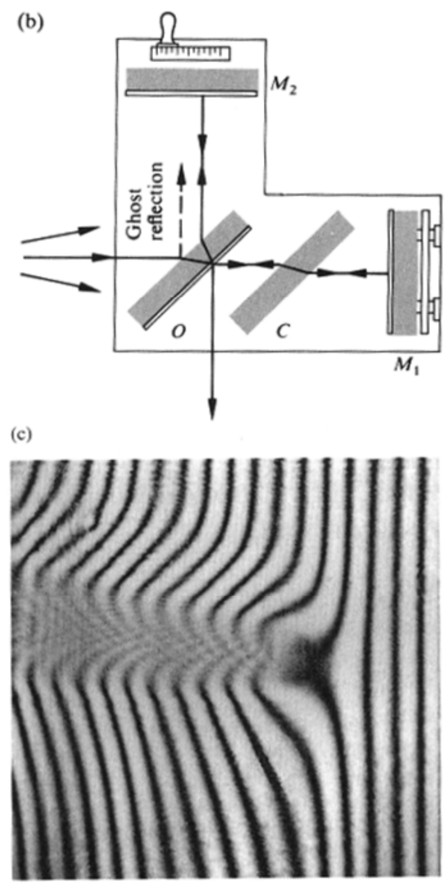



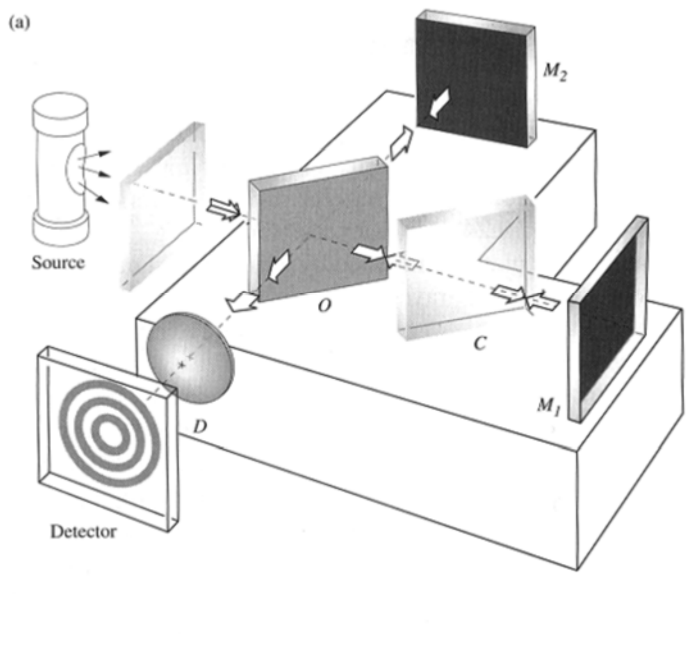

**Figure 9.24** The Michelson Interferometer. (*a*) Circular fringes are centered on the lens. (*b*) Top view of the interferometer showing the path of the light. (*c*) A wedge fringe pattern was distorted when the tip of a hot soldering iron was placed in one arm. Observe the interesting perceptual phenomenon whereby the region corresponding to the iron's tip appears faintly yellow. (Photo by E. H.)

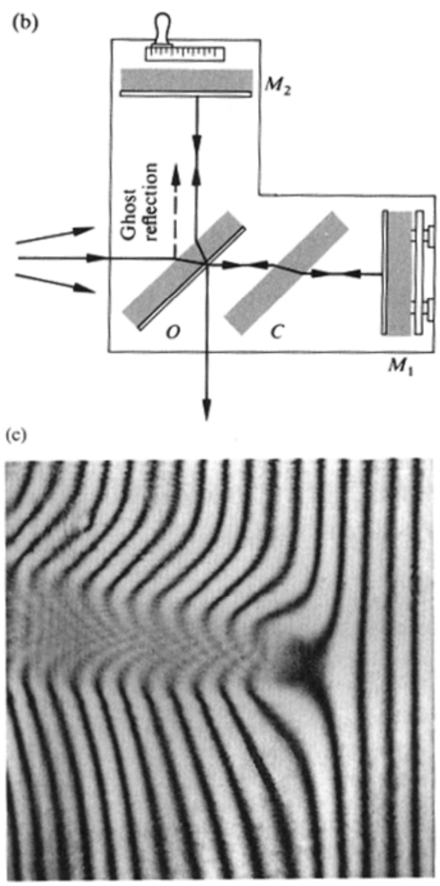
# Michelson Interferometer

- At detector two beams combine to create interference
- Let path length difference be $\Delta l$
- Then if $\Delta l = N\lambda/2$ get constructive interference – bright
- Dark if

$$\Delta l = \frac{2N+1}{4}\lambda$$

- Now can measure very small distance changes
- Eg if put glass plate C in can see small defects in glass
- Interferometers used in measuring distance
- Digitize light level and measure changes – can get $\lambda/64$ or 256
- Measure 2 nm distance
- Need extremely stable laser

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## Michelson Interferometer

- Actually see circular interference at the detector
- Reason distance from detector to splitter is d
- The angle θ at the detector when destructive interference is

$$2d\cos(\theta_m) = m\lambda$$

- Result is rings of interference

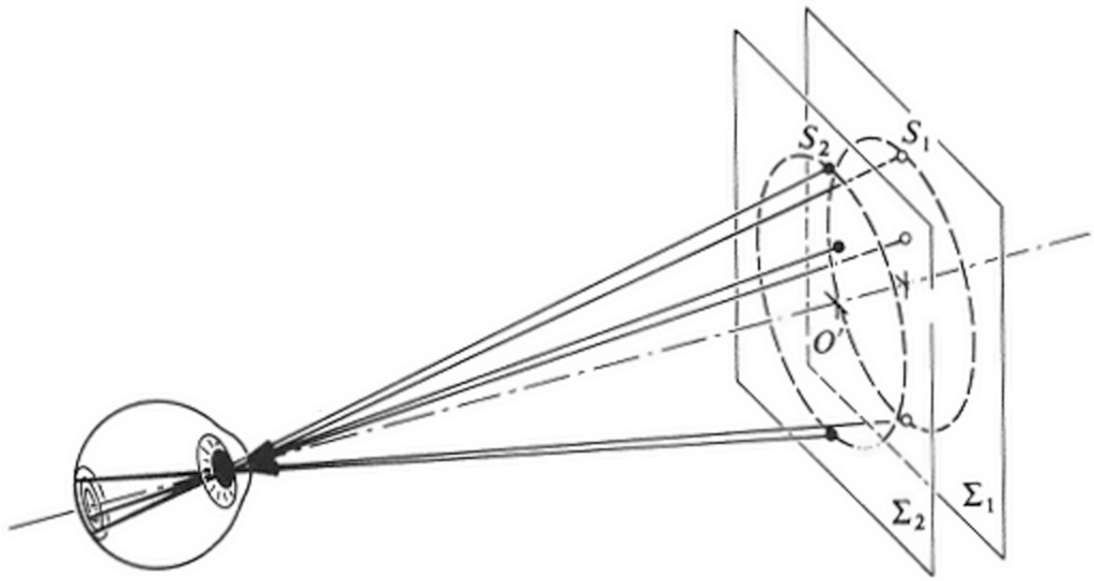


**Figure 9.26** Formation of circular fringes.

## Michelson Morley Experiment

- Use Michelson interferometer floating on mercury
- Align so path along direction of earth around sun
- Other path at along radius to sun
- Then rotate by 90 degrees
- Classic physics: Along the path in direction of motion
- light should arrive sooner to addition of velocities
- But no difference found – first indication of relativity