Plane waves

- Far from the antenna, the EM waves are well described as *plane waves* – the fields are uniform within planes perpendicular to the direction of propagation.
- Sinusoidal waves – fields are sinusoidal functions of position and time.
  - E.g. wave moving along x axis:

$$\vec{\mathbf{E}} = E_0 \sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}\right)\hat{\mathbf{j}} = E_0 \sin(kx - \omega t)\hat{\mathbf{j}}$$

$$\vec{\mathbf{B}} = B_0 \sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}\right)\hat{\mathbf{k}} = B_0 \sin(kx - \omega t)\hat{\mathbf{k}}$$

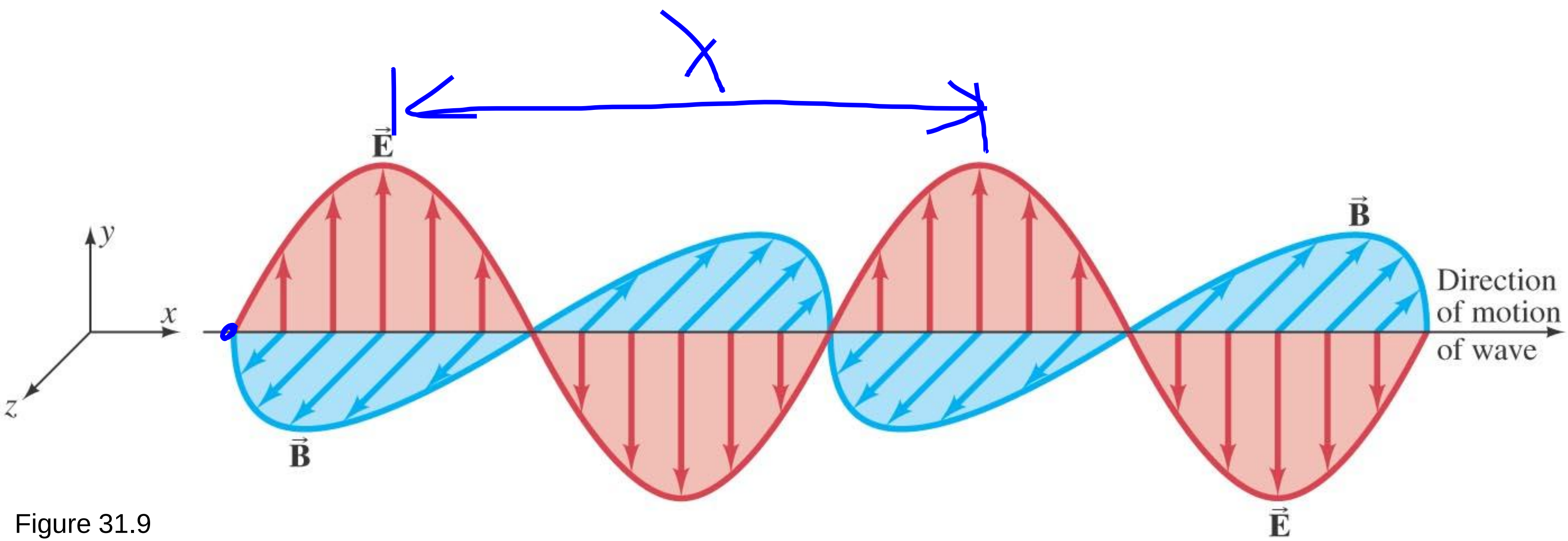


Figure 31.9

$$\vec{\mathbf{E}} = E_0 \sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}\right)\hat{\mathbf{j}} = E_0 \sin(kx - \omega t)\hat{\mathbf{j}}$$

$$c = \frac{\lambda}{T} = \lambda f$$

$$\vec{\mathbf{B}} = B_0 \sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}\right)\hat{\mathbf{k}} = B_0 \sin(kx - \omega t)\hat{\mathbf{k}}$$

Light wave A has twice the frequency of light wave B. The wavelength of light wave A is ______ that of light wave B.

1) equal to
2) twice
3) four times
4) half
5) one

Phase

- The phase of a wave is the angular argument of a sinusoidal wave function:

$$\vec{\mathbf{E}} = E_0 \sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}\right)\hat{\mathbf{j}} = E_0 \sin(kx - \omega t)\hat{\mathbf{j}}$$

$= \phi$

- Relative phase (phase difference) between two waves $\Delta\phi$:
  - The time (distance) between peaks of the two waves relative to the wave period (wavelength).

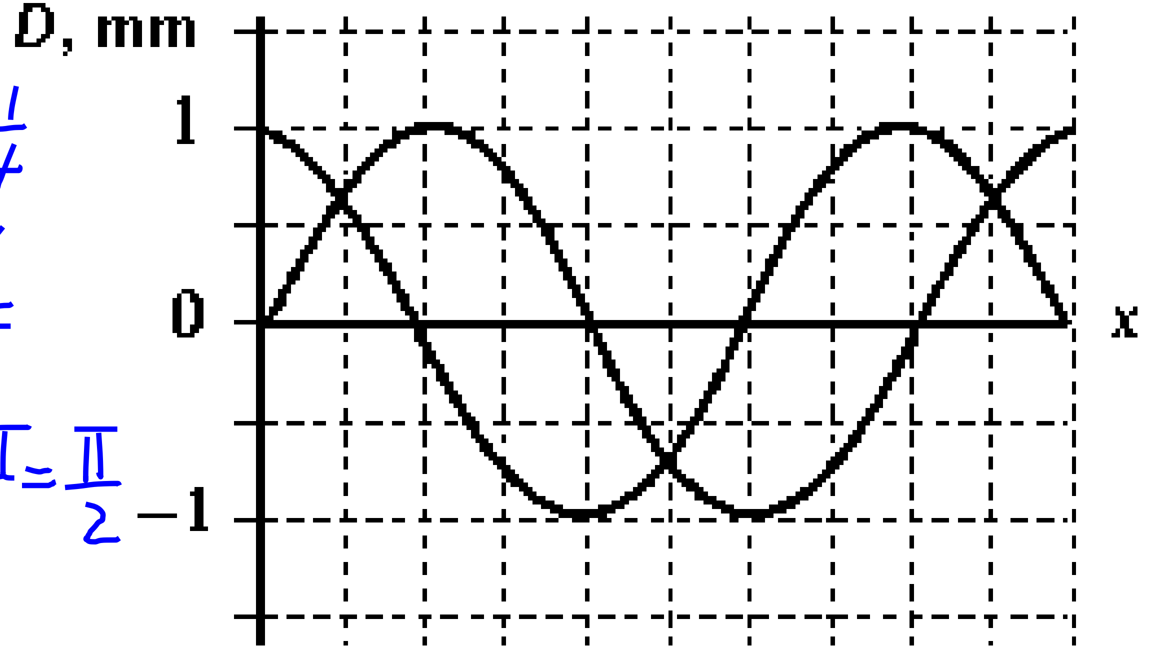
$$\frac{\Delta\phi}{2\pi} = \frac{\Delta x}{\lambda} = \frac{\Delta t}{T}$$

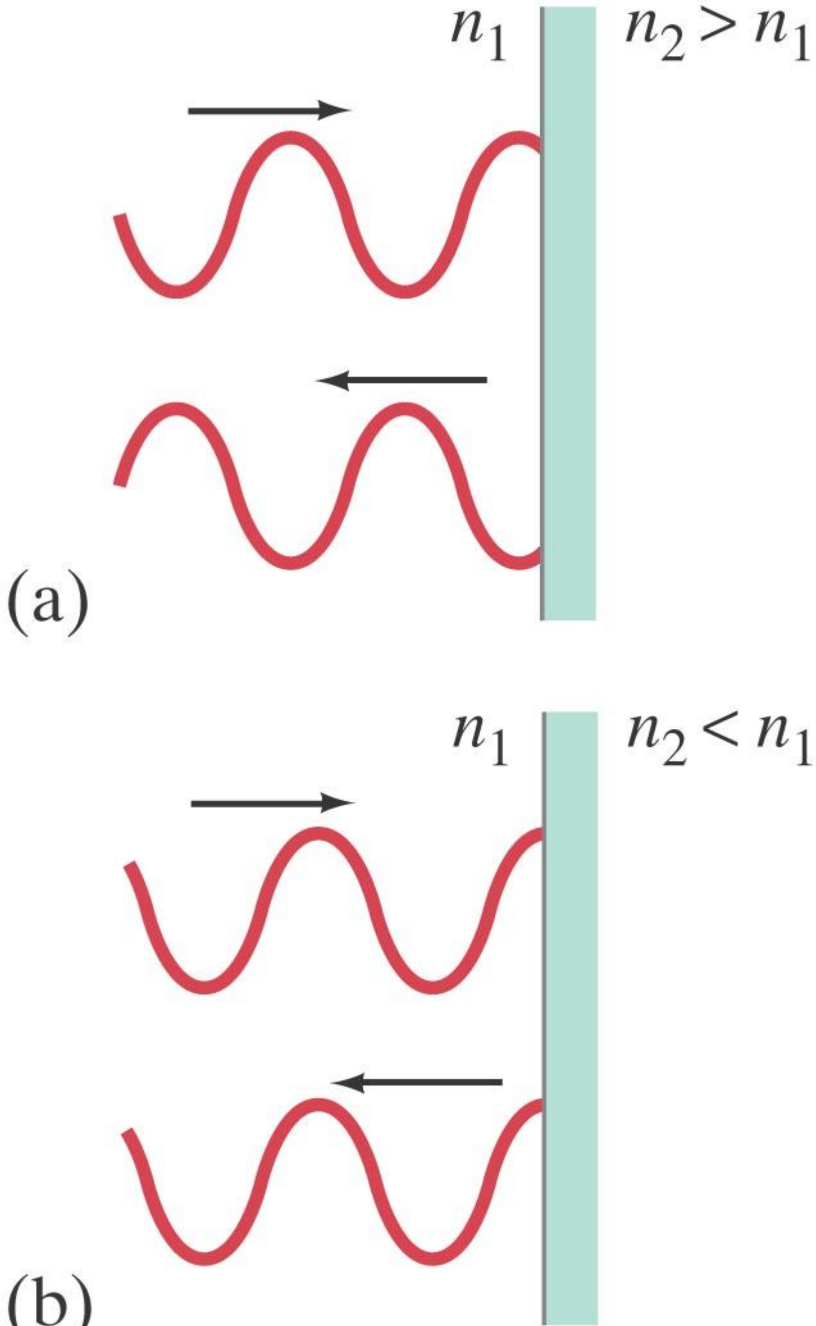
The phase difference for the two waves shown in the figure is

1) 2π
2) π
3) $2\pi/3$
4) $\pi/2$
5) It is not possible to answer this question without additional information.

$$\frac{\Delta x}{\lambda} = \frac{2}{8} = \frac{1}{4} = \frac{\Delta \phi}{2\pi}$$

$$\Delta \phi = \frac{2\pi}{4} = \frac{\pi}{2}$$





Reflection Phase Shifts

When a wave reflects off of a medium with a higher index of refraction, the reflected wave has a π phase shift (is inverted) relative to the incident wave.

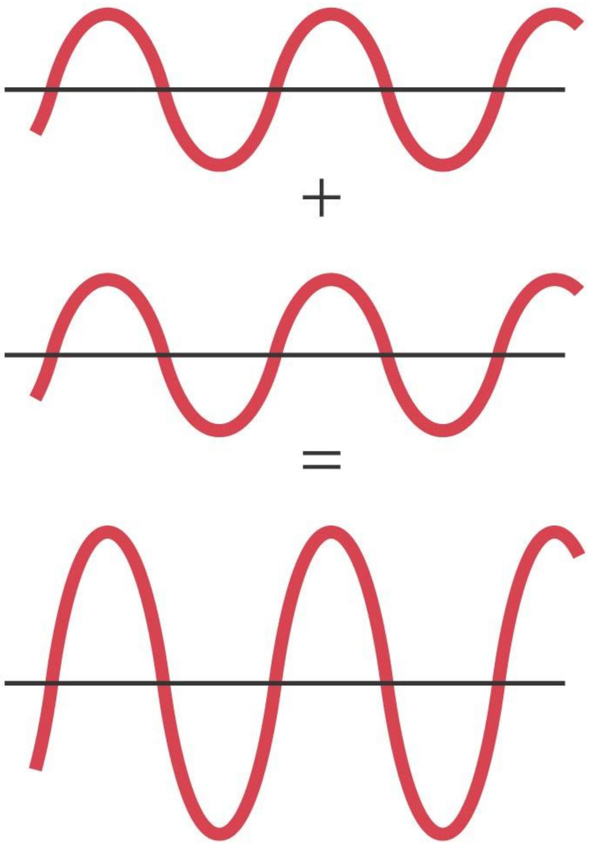
When a wave reflects off of a medium with a lower index of refraction, the reflected wave has no phase shift relative to the incident wave.

Figure

Interference

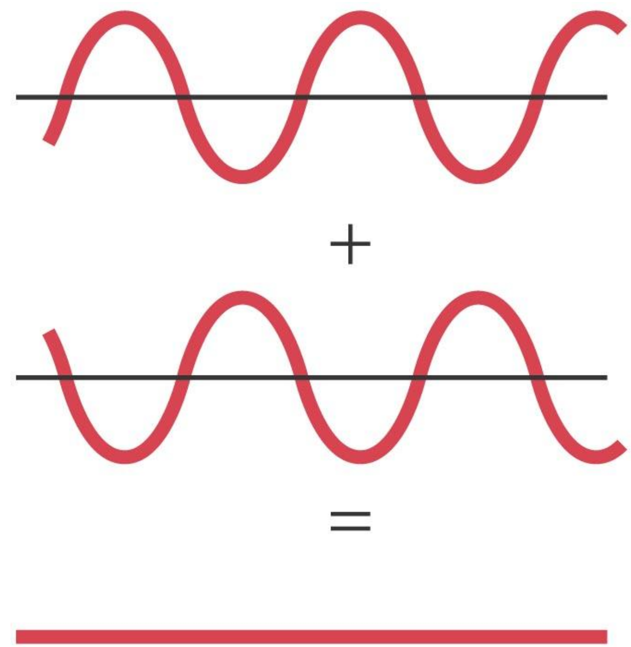
When two waves meet at some point in space, the waves at each instant of time simply add (principle of superposition).

Constructive Interference
(Waves “in phase”)



(a)

Completely Destructive Interference
(Waves “out of phase”)

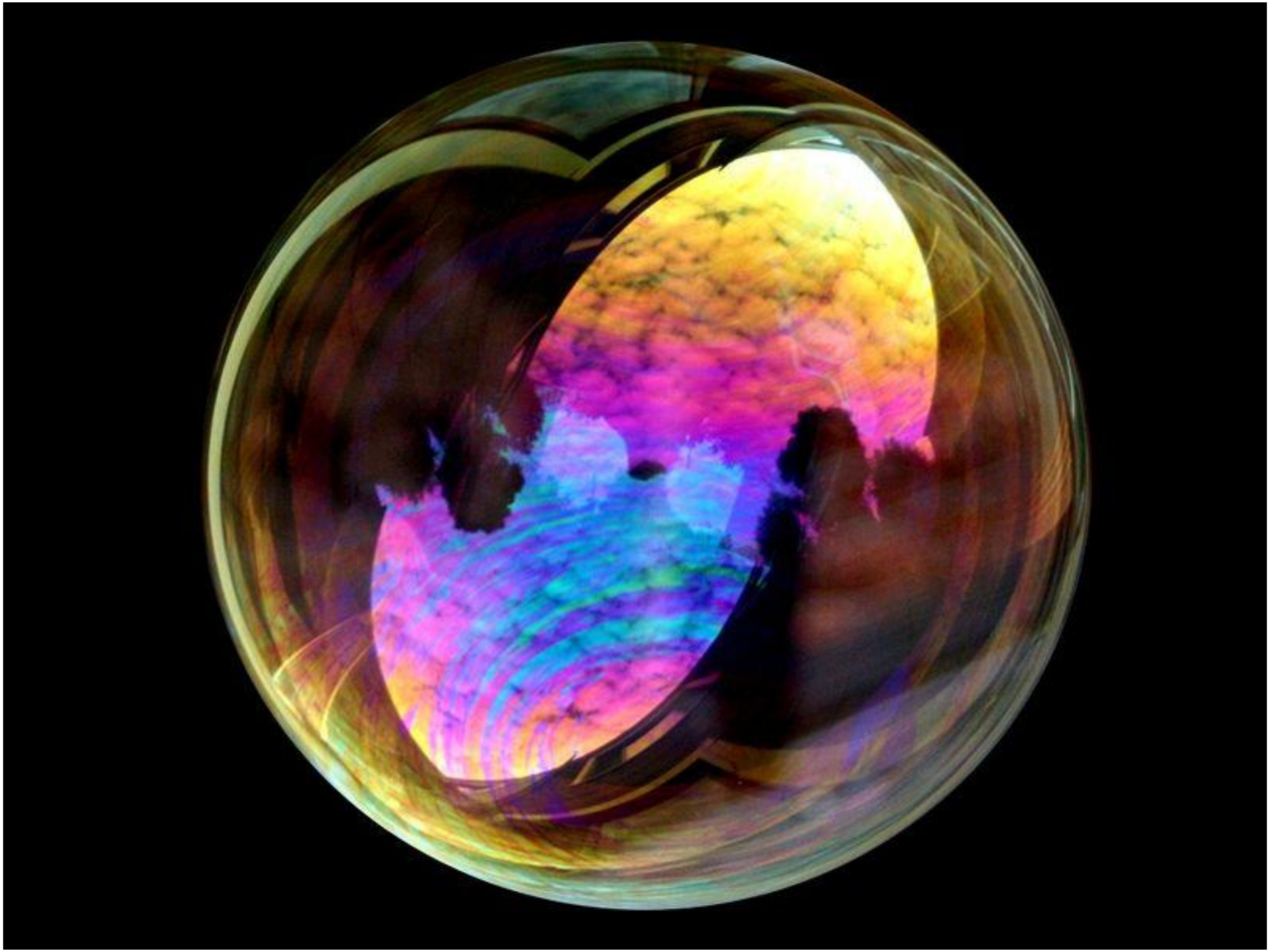


(b)

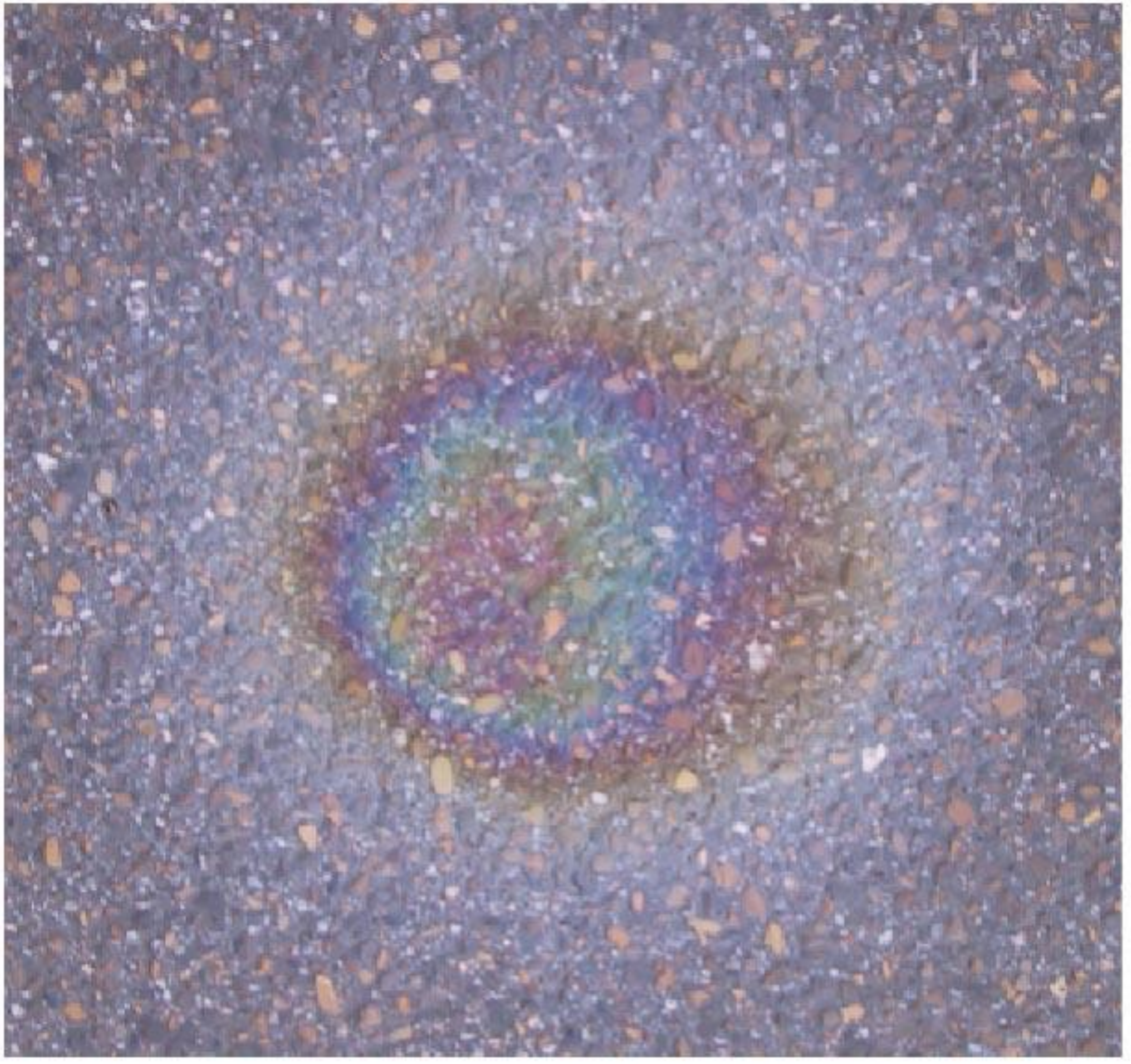
Figure 34.8a

For two identical rays of light to interfere destructively, their phases

1) must be equal.
2) must differ by an odd multiple of π.
3) must differ by an even multiple of π.
4) must differ by any multiple of π.



http://twilit.files.wordpress.com/2008/03/soap-bubble.jpg



(c)

Figure 34.16c

Thin-film interference

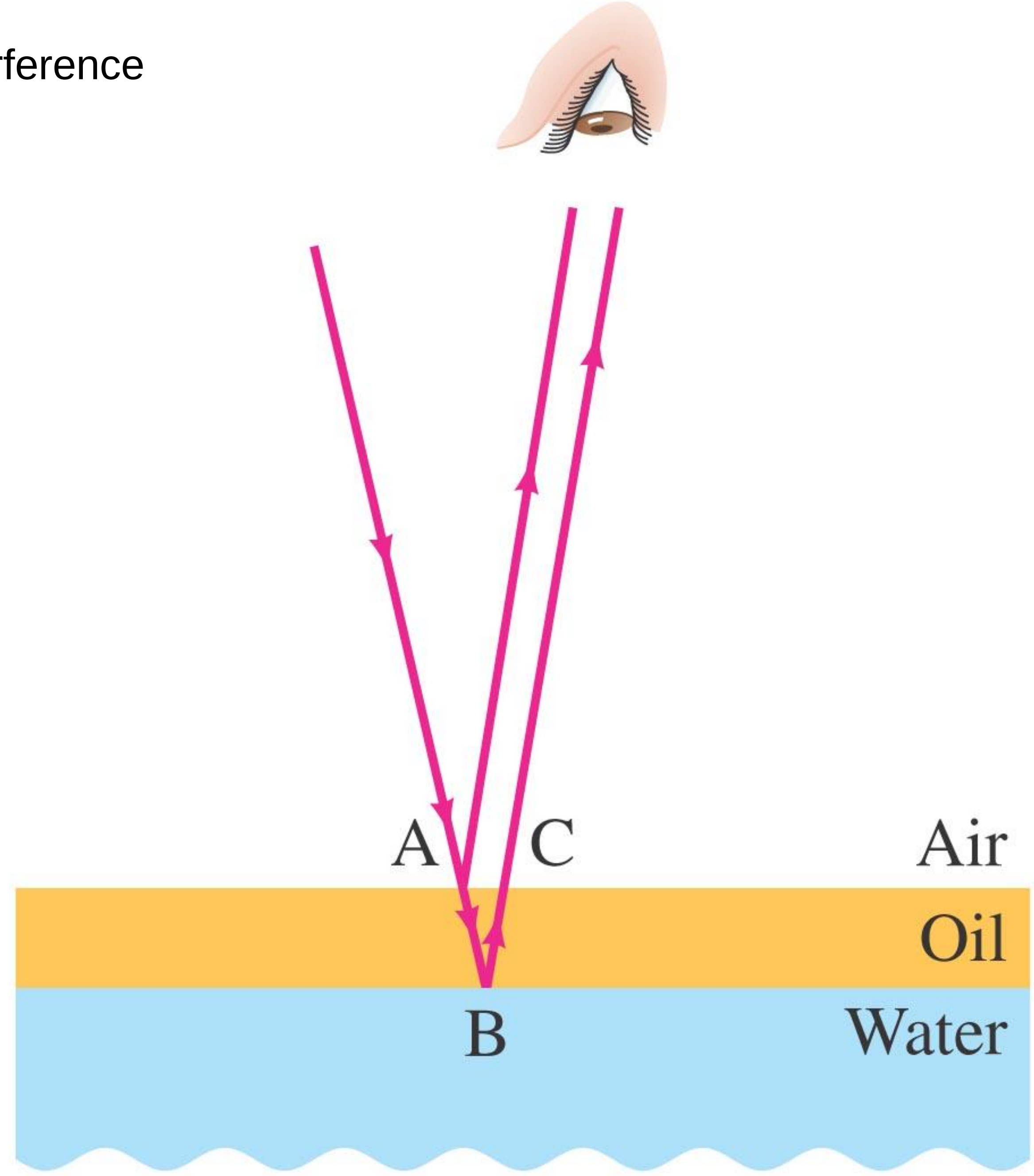
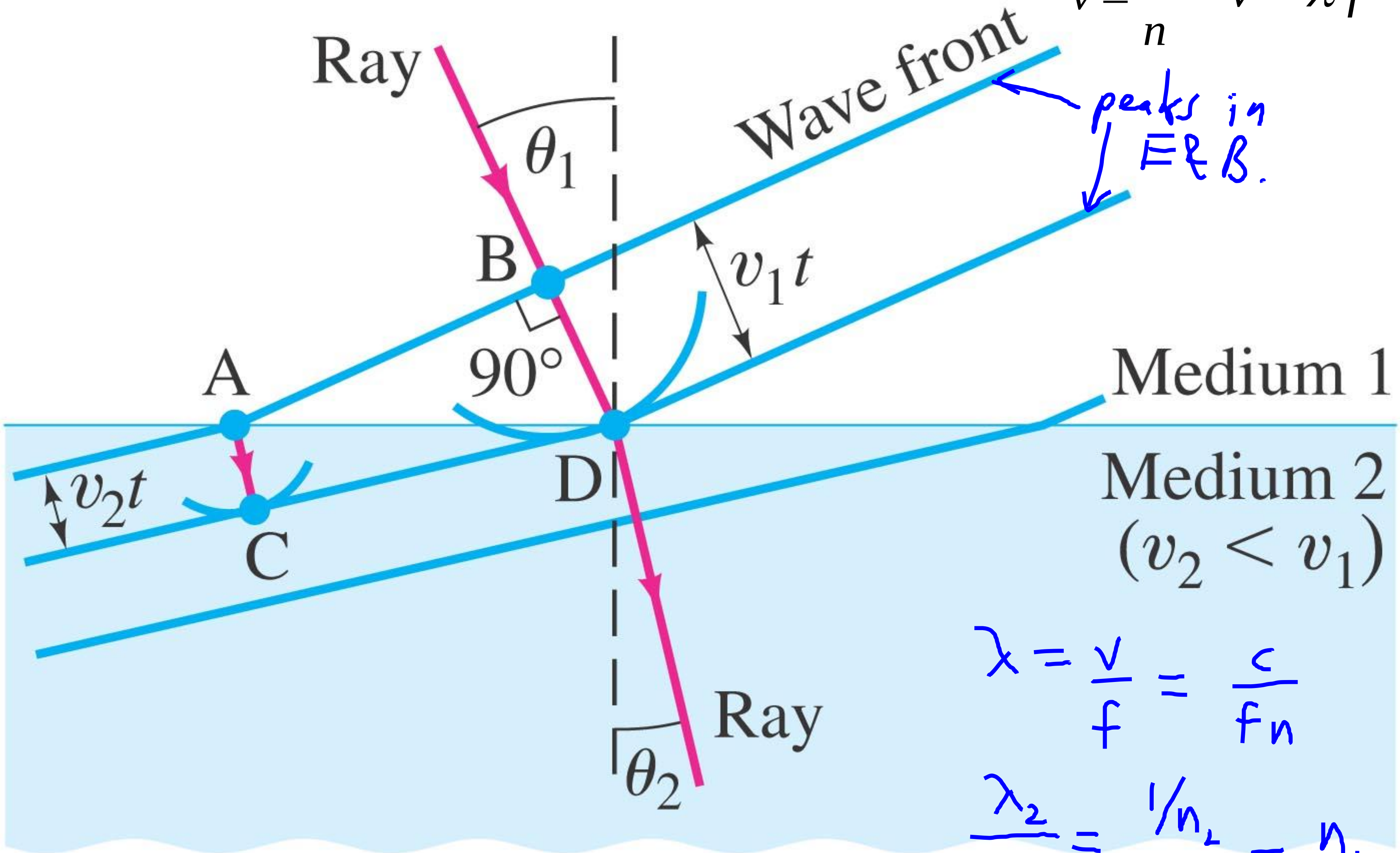


Figure 34.17

$$v = \frac{c}{n} \qquad v = \lambda f$$

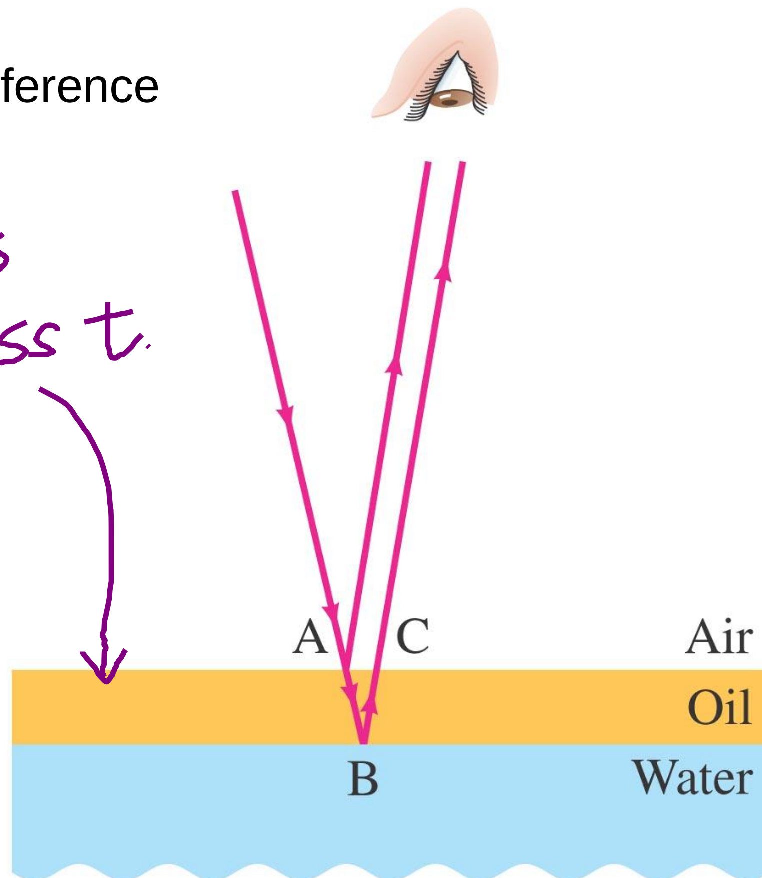


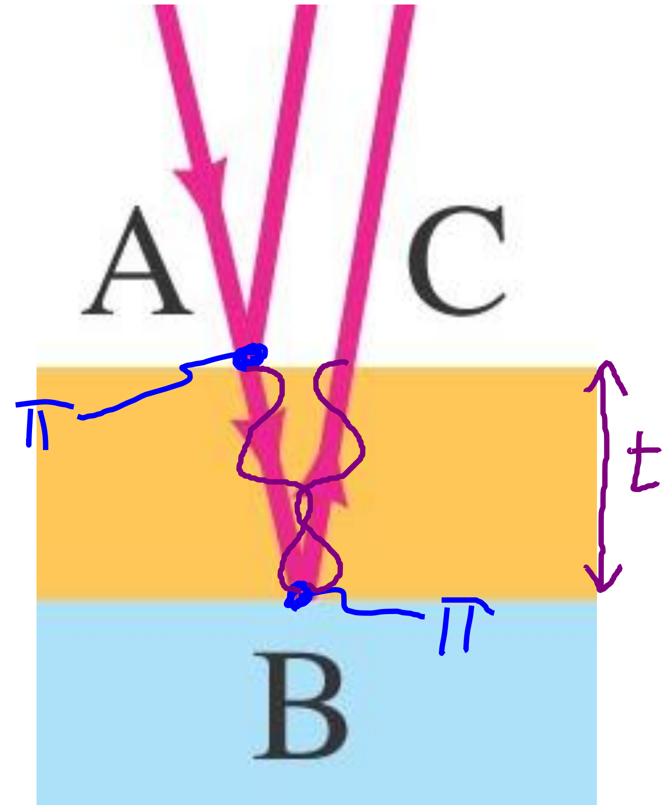
$$\lambda = \frac{v}{f} = \frac{c}{fn}$$

$$\frac{\lambda_2}{\lambda_1} = \frac{1/n_2}{1/n_1} = \frac{n_1}{n_2}$$

Figure 34.3

Thin-film interference





Film has thickness t.

$$\frac{\lambda_2}{\lambda_1} = \frac{n_1}{n_2}$$

$$\Delta x = 2t$$

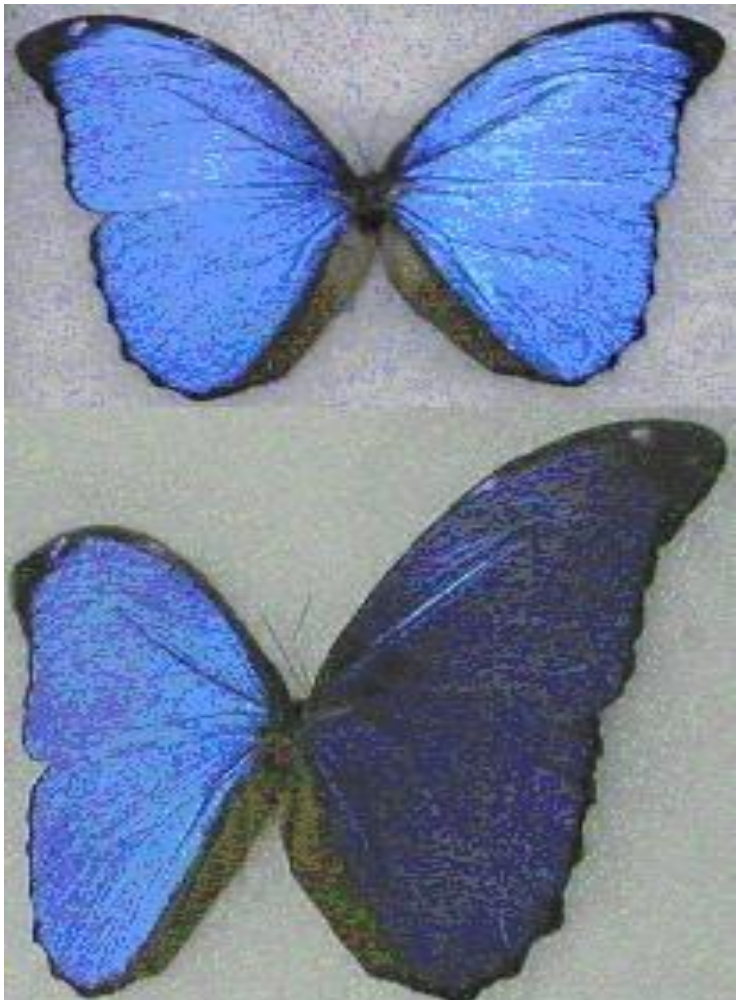
for constructive

$$\frac{\Delta\phi}{2\pi} = \frac{\Delta x}{\lambda_2} = \frac{2t}{\lambda_2} = 0, 1, 2, 3 \ldots$$

$$\frac{2t\, n_2}{n_1 \lambda_1} = 0, 1, 2, \ldots$$

Figure 34.17

Blue Morpho Iridescent Butterfly



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Color generation in butterfly wings and fabrication of such structures

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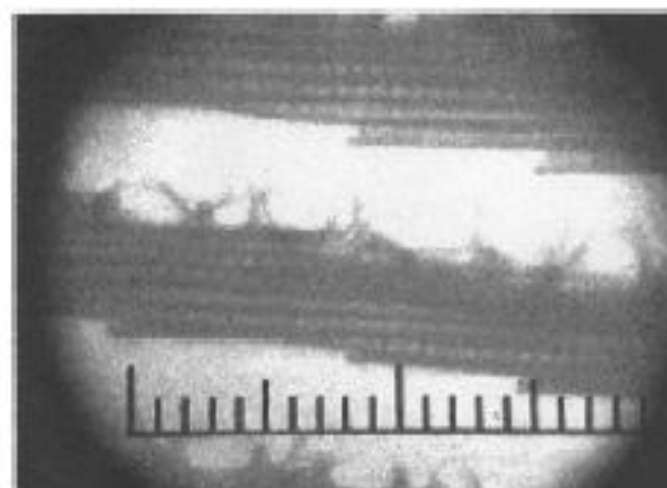

Fig. 1. TEM image of the ridges and layer structures for a morpho butterfly wing.