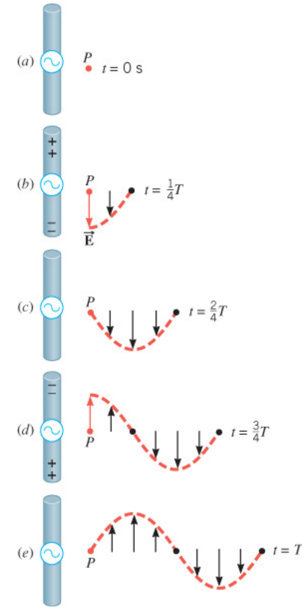
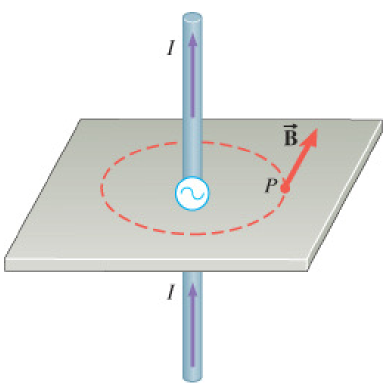
Chapter 24

Electromagnetic Waves



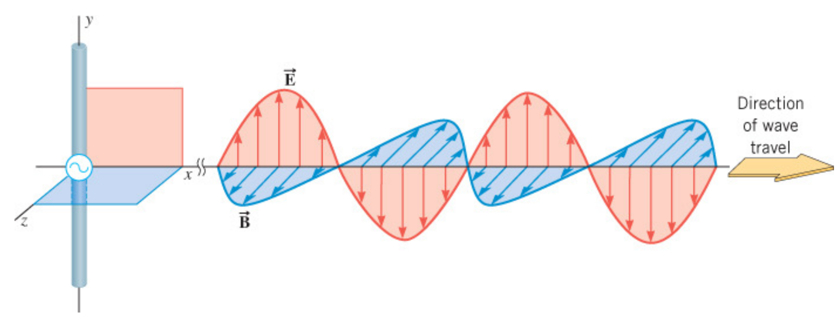
Two straight wires connected to the terminals of an AC generator can create an ***electromagnetic wave***.

Only the electric wave traveling to the right is shown here.



The current used to generate the electric wave creates a magnetic field.

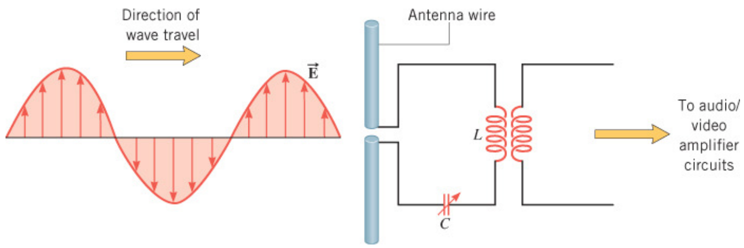
This picture shows the wave of the radiation field far from the antenna.



The speed of an electromagnetic wave in a vacuum is:

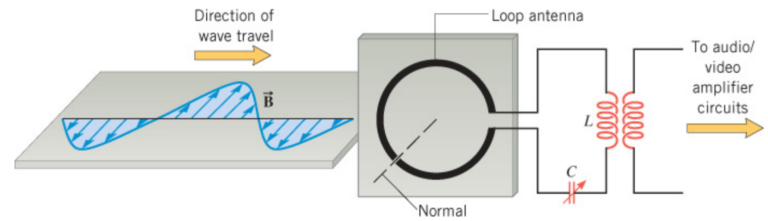
$$c = 3.00\times10^{8}\ \mathrm{m/s}$$

24.1 The Nature of Electromagnetic Waves



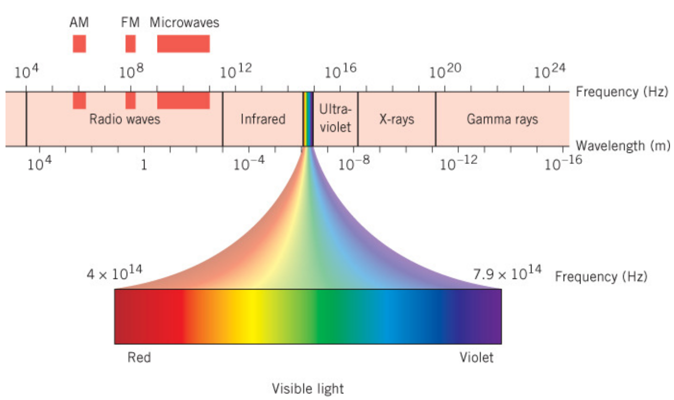
A radio wave can be detected with a receiving antenna wire that is parallel to the electric field.

24.1 The Nature of Electromagnetic Waves



With a receiving antenna in the form of a loop, the magnetic field of a radio wave can be detected.

24.2 The Electromagnetic Spectrum



Like all waves, electromagnetic waves have a wavelength and frequency, related by:

$$c = f\lambda$$

24.2 The Electromagnetic Spectrum

Example 1 **The Wavelength of Visible Light**

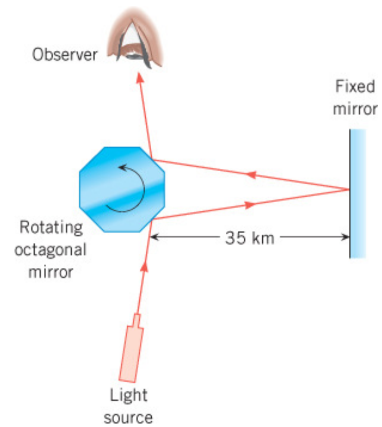
Find the range in wavelengths for visible light in the frequency range between 4.0x10^{14}Hz and 7.9x10^{14}Hz.

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{4.0\times10^{14}\ \text{Hz}} = 7.5\times10^{-7}\ \text{m} = 750\ \text{nm}$$

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{7.9\times10^{14}\ \text{Hz}} = 3.8\times10^{-7}\ \text{m} = 380\ \text{nm}$$

Conceptual Example 2 The Diffraction of AM and FM Radio Waves

Diffraction is the ability of a wave to bend around an obstacle or the edges of an opening. Would you expect AM or FM radio waves to bend more readily around an obstacle such as a building?

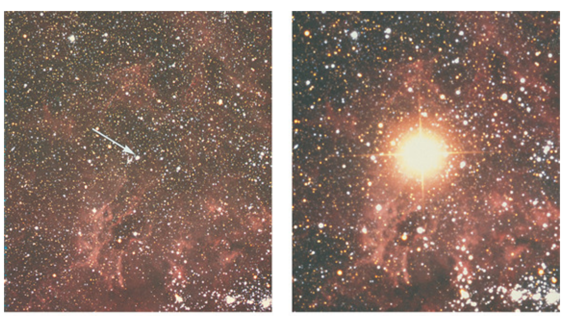


The speed of light in a vacuum

$$c = 299\,792\,458 \text{ m/s}$$

Conceptual Example 3 Looking Back in Time

A supernova is a violent explosion that occurs at the death of certain stars. The figure shows a photograph of the sky before and after a supernova. Why do astronomers say that viewing an event like this is like looking back in time?



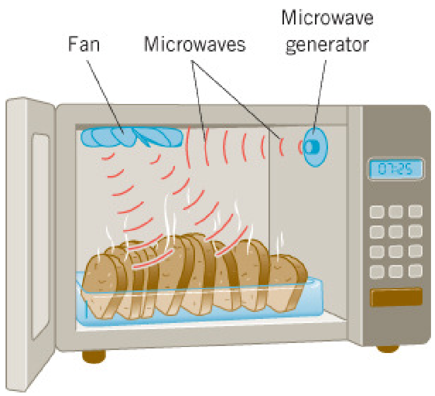
(*a*) (*b*)

Maxwell's prediction of the speed of light

$$c = \frac{1}{\sqrt{\varepsilon_o \mu_o}} = \frac{1}{\sqrt{\left(8.85\times10^{-12}\ \text{C}^2/\left(\text{N}\cdot\text{m}^2\right)\right)\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)}} = 3.00\times10^{8}\ \text{m/s}$$

24.4 The Energy Carried by Electromagnetic Waves

Electromagnetic waves, like water waves, carry energy.

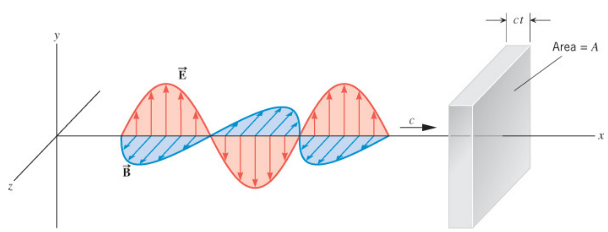


24.4 The Energy Carried by Electromagnetic Waves

The total energy density carried by an electromagnetic wave

$$u = \frac{\text{Total energy}}{\text{Volume}} = \frac{1}{2}\varepsilon_o E^2 + \frac{1}{2\mu_o} B^2$$

24.4 The Energy Carried by Electromagnetic Waves



$$S = \frac{P}{A} = \frac{\text{Total energy}}{t\,A} = \frac{uctA}{tA} = cu$$

24.5 The Doppler Effect and Electromagnetic Waves

Electromagnetic waves also can exhibit a Dopper effect, but it differs for two reasons:

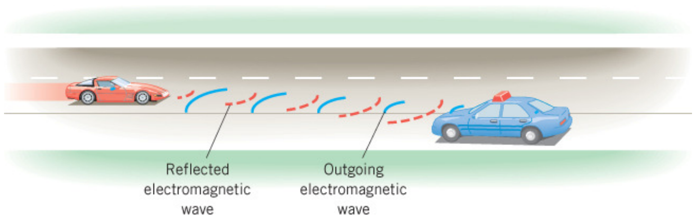
a) Sound waves require a medium, whereas electromagnetic waves do not.

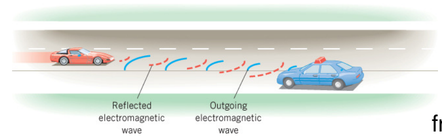
b) For sound, it is the motion relative to the medium that is important. For electromagnetic waves, only the relative motion of the source and observer is important.

$$f_o = f_s\left(1 \pm \frac{v_{\text{rel}}}{c}\right) \qquad \text{if} \quad v_{\text{rel}} << c$$

Example 6 Radar Guns and Speed Traps

The radar gun of a police car emits an electromagnetic wave with a frequency of 8.0x10^{9}Hz. The approach is essentially head on. The wave from the gun reflects from the speeding car and returns to the police car, where on-board equipment measures its frequency to be greater than the emitted wave by 2100 Hz. Find the speed of the car with respect to the highway. The police car is parked.





frequency "observed" by speeding car

$$f_o = f_s\left(1+\frac{v_{\text{rel}}}{c}\right)$$

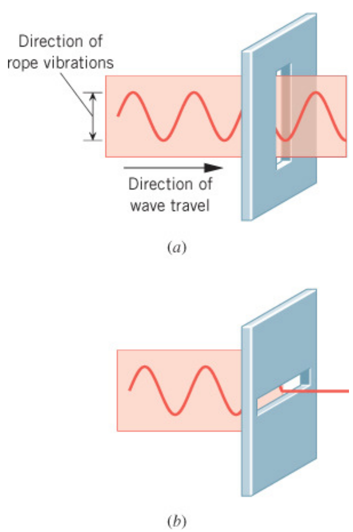
frequency observed by police car

$$f_o' = f_o\left(1+\frac{v_{\text{rel}}}{c}\right)$$

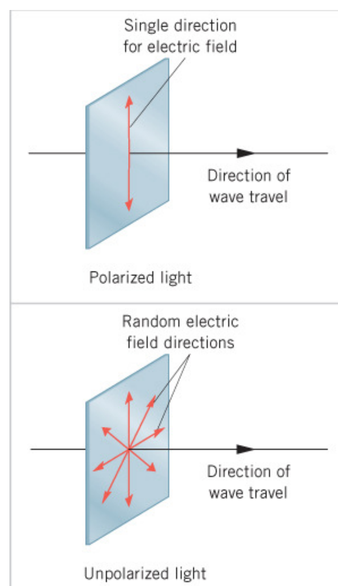
$$f_o' - f_s = f_o - f_s + f_o\left(\frac{v_{\text{rel}}}{c}\right) - f_s\left(\frac{v_{\text{rel}}}{c}\right) \approx 2f_s\left(\frac{v_{\text{rel}}}{c}\right)$$

$$v_{\text{rel}} \approx \left(\frac{f_o' - f_s}{2f_s}\right)c = \left[\frac{2100\ \text{Hz}}{2(8.0\times10^8\ \text{Hz})}\right](3.0\times10^8\ \text{m/s}) = 39\ \text{m/s}$$

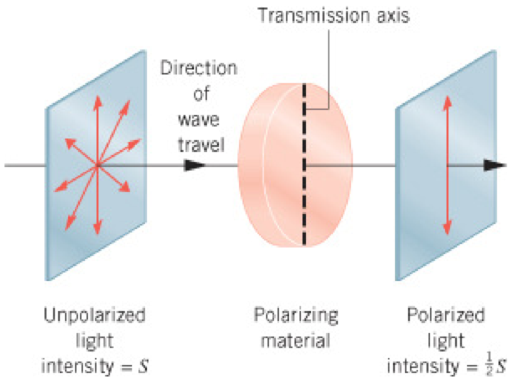
POLARIZED ELECTROMAGNETIC WAVES



Linearly polarized wave on a rope.

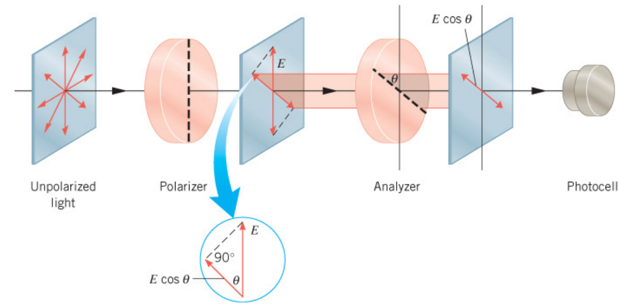


In polarized light, the electric field fluctuates along a single direction.



Polarized light may be produced from unpolarized light with the aid of polarizing material.

MALUS' LAW



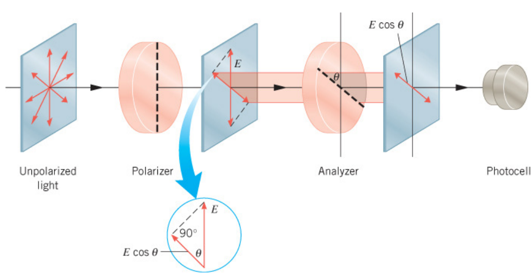
$$\bar{S} = \bar{S}_o \cos^2\theta$$

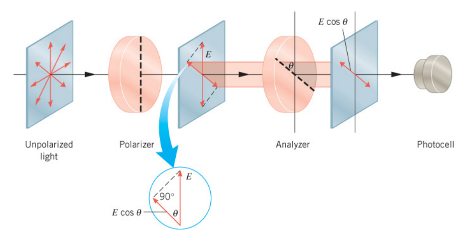
intensity after analyzer

intensity before analyzer

Example 7 Using Polarizers and Analyzers

What value of θ should be used so the average intensity of the polarized light reaching the photocell is one-tenth the average intensity of the unpolarized light?



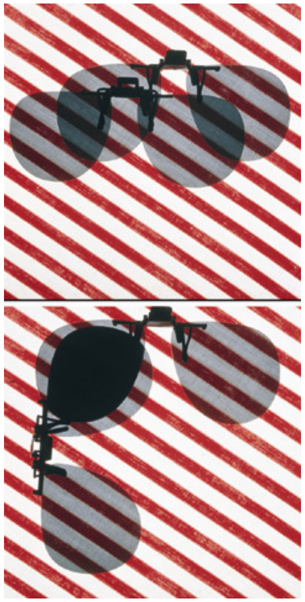


$$\tfrac{1}{10}\bar{S}_o = \left(\tfrac{1}{2}\bar{S}_o\right)\cos^2\theta$$

$$\tfrac{1}{5} = \cos^2\theta$$

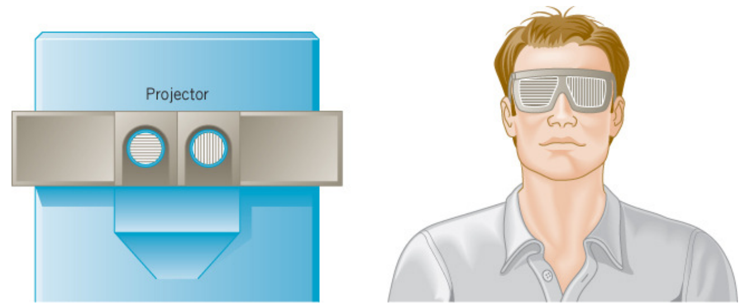
$$\cos\theta = \sqrt{\tfrac{1}{5}}$$

$$\theta = 63.4^\circ$$



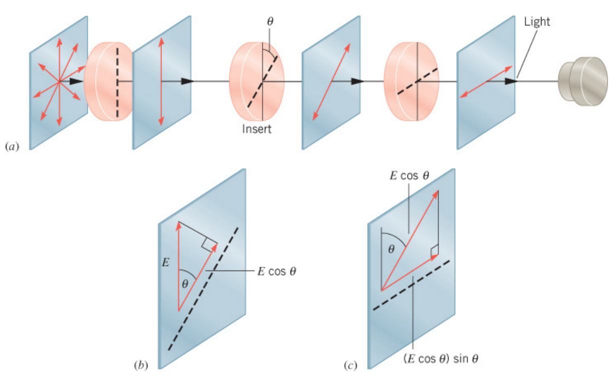
When Polaroid sunglasses are crossed, the intensity of the transmitted light is reduced to zero.

IMAX movie projector



Conceptual Example 8 How Can a Crossed Polarizer and Analyzer Transmit Light?

Suppose that a third piece of polarizing material is inserted between the polarizer and analyzer. Does light now reach the photocell?



THE OCCURANCE OF POLARIZED LIGHT IN NATURE