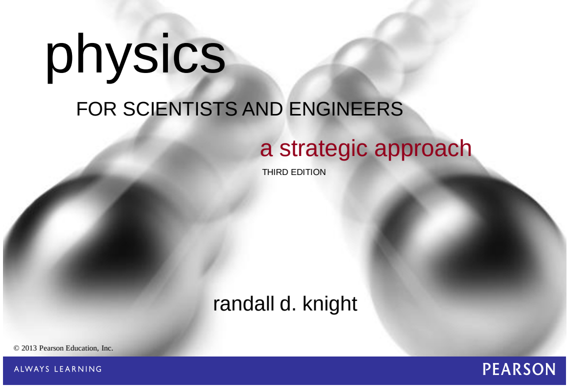
Class 2, Sections 20.4-20.7 Preclass Notes



physics

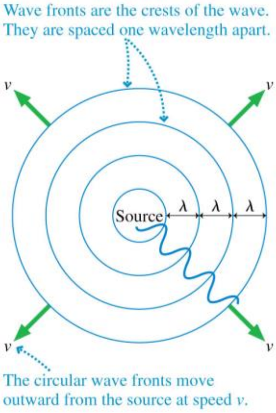
FOR SCIENTISTS AND ENGINEERS

a strategic approach

THIRD EDITION

randall d. knight

ALWAYS LEARNING PEARSON

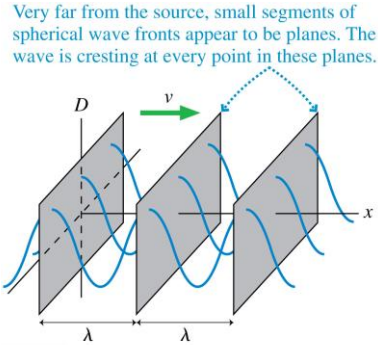


Wave fronts are the crests of the wave. They are spaced one wavelength apart.

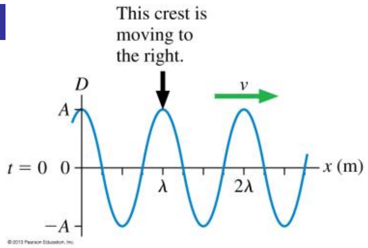
The circular wave fronts move outward from the source at speed *v*.

Waves in Two and Three Dimensions

- Loudspeakers and lightbulbs emit **spherical waves.**
- That is, the crests of the wave form a series of concentric spherical shells.
- Far from the source this is a **plane wave.**



Very far from the source, small segments of spherical wave fronts appear to be planes. The wave is cresting at every point in these planes.



This crest is moving to the right.

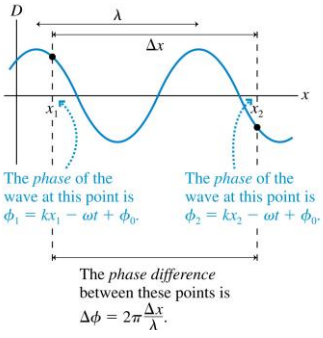
- Recall:
- The displacement caused by a traveling sinusoidal wave is:

$$D(x, t) = A\sin(kx - \omega t + \phi_0)$$

(sinusoidal wave traveling in the positive *x*-direction)

Phase and Phase Difference

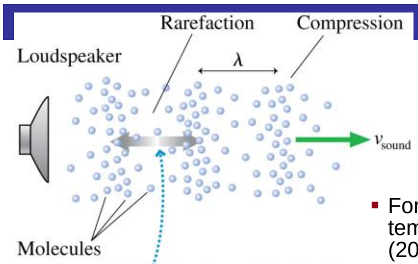
- The quantity $(kx - \omega t + \phi_0)$ is called the **phase** of the wave, denoted ϕ.
- The *phase* difference $\Delta\phi$ between two points on a wave depends on only the ratio of their separation Δx to the wavelength λ.
- The phase difference between two adjacent wave fronts is 2π rad.



The *phase* of the wave at this point is $\phi_1 = kx_1 - \omega t + \phi_0$.

The *phase* of the wave at this point is $\phi_2 = kx_2 - \omega t + \phi_0$.

The *phase difference* between these points is $\Delta\phi = 2\pi\frac{\Delta x}{\lambda}$.



Individual molecules oscillate back and forth with displacement *D*. As they do so, the compressions propagate forward at speed v_{sound}. Because compressions are regions of higher pressure, a sound wave can be thought of as a pressure wave.

- For air at room temperature (20°C), the speed of sound is $v_{\text{sound}} = 343$ m/s.

Sound Waves

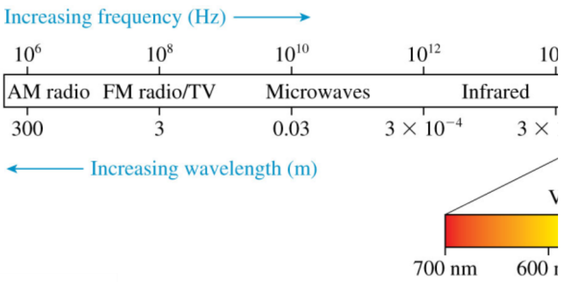
- Your ears are able to detect sinusoidal sound waves with frequencies between about 20 Hz and 20 kHz.
- Low frequencies are perceived as “low pitch” bass notes, while high frequencies are heard as “high pitch” treble notes.
- Sound waves with frequencies above 20 kHz are called *ultrasonic* frequencies.
- Oscillators vibrating at frequencies of many MHz generate the ultrasonic waves used in ultrasound medical imaging.

Electromagnetic Waves

- A light wave is an *electromagnetic wave*, an oscillation of the electromagnetic field.
- Other electromagnetic waves, such as radio waves, microwaves, and ultraviolet light, have the same physical characteristics as light waves, even though we cannot sense them with our eyes.

- All electromagnetic waves travel through vacuum with the same speed, called the *speed of light.*
- The value of the speed of light is $c = 299{,}792{,}458$ m/s.
- At this speed, light could circle the earth 7.5 times in a mere second—if there were a way to make it go in circles!

The Electromagnetic Spectrum



The Index of Refraction

- Light waves travel with speed *c* in a vacuum, but they slow down as they pass through transparent materials such as water or glass or even, to a very slight extent, air.
- The speed of light in a material is characterized by the material’s **index of refraction** n, defined as

$$n = \frac{c}{v}$$

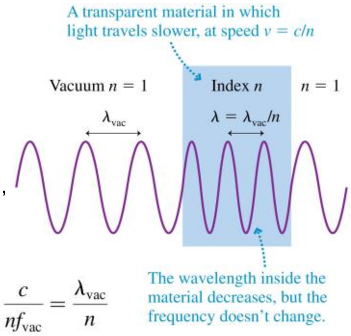
TABLE 20.2 Typical indices of refraction

Material	Index of refraction
Vacuum	1 exactly
Air	1.0003
Water	1.33
Glass	1.50
Diamond	2.42

[image of cup from http://etc.usf.edu/clippix/picture/refraction-of-pencil-in-cup-of-water.html]

The Index of Refraction

- As a light wave travels through vacuum it has wavelength λ_{vac} and frequency f_{vac}.
- When it enters a transparent material, the frequency does not change, so the wavelength must:



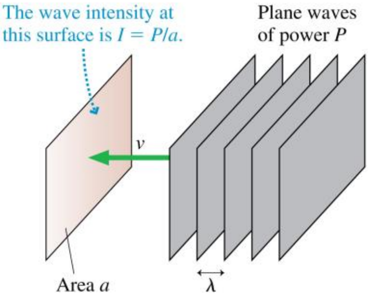
A transparent material in which light travels slower, at speed $v = c/n$

The wavelength inside the material decreases, but the frequency doesn’t change.

$$\lambda_{\text{mat}} = \frac{v}{f_{\text{mat}}} = \frac{c}{nf_{\text{mat}}} = \frac{c}{nf_{\text{vac}}} = \frac{\lambda_{\text{vac}}}{n}$$

Power and Intensity

- The *power* of a wave is the rate, in joules per second, at which the wave transfers energy.
- When plane waves of power P impinge on area a we define the **intensity** I to be:



The wave intensity at this surface is $I = P/a$.

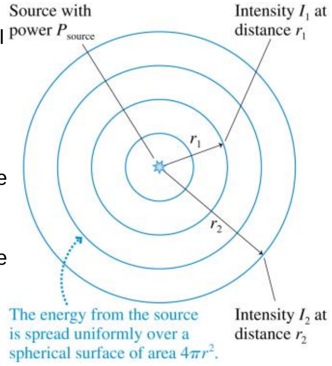
Plane waves of power P

$$I = \frac{P}{a} = \text{power-to-area ratio}$$

Intensity of Spherical Waves

- If a source of spherical waves radiates uniformly in all directions, then the power at distance *r* is spread uniformly over the surface of a sphere of radius *r.*
- The intensity of a uniform spherical wave is:

$$I = \frac{P_{\text{source}}}{4\pi r^2}$$



The energy from the source is spread uniformly over a spherical surface of area $4\pi r^2$.

Intensity and Decibels

- Human hearing spans an extremely wide range of intensities, from the *threshold of hearing* at $\approx 1 \times 10^{-12}\ \text{W/m}^2$ (at midrange frequencies) to the *threshold of pain* at $\approx 10\ \text{W/m}^2$.
- If we want to make a scale of loudness, it's convenient and logical to place the zero of our scale at the threshold of hearing.
- To do so, we define the **sound intensity level**, expressed in **decibels** (dB), as:

$$\beta = (10\ \text{dB}) \log_{10}\left(\frac{I}{I_0}\right)$$

where $I_0 = 1 \times 10^{-12}\ \text{W/m}^2$.

[image of ear from http://www.palmbeachdentist.com/blog/2012/04/10/lack-of-saliva-after-inner-ear-surgery/]

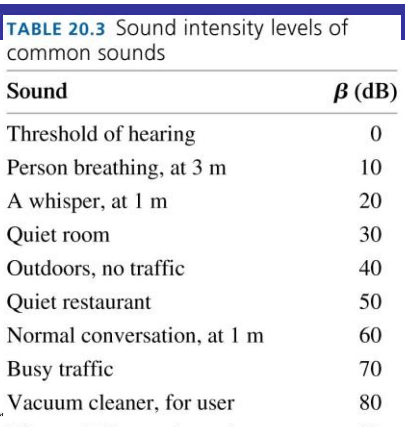
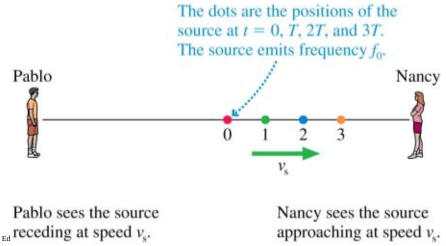


TABLE 20.3 Sound intensity levels of common sounds

Sound	β (dB)
Threshold of hearing	0
Person breathing, at 3 m	10
A whisper, at 1 m	20
Quiet room	30
Outdoors, no traffic	40
Quiet restaurant	50
Normal conversation, at 1 m	60
Busy traffic	70
Vacuum cleaner, for user	80

The Doppler Effect

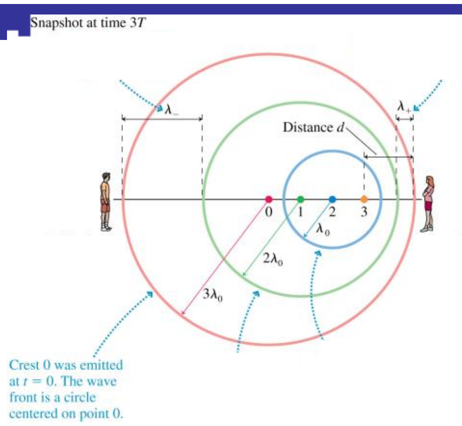
- A source of sound waves moving away from Pablo and toward Nancy at a steady speed v_s.
- After a wave crest leaves the source, its motion is governed by the properties of the medium.



The dots are the positions of the source at $t = 0, T, 2T,$ and $3T$. The source emits frequency f_0.

Pablo sees the source receding at speed v_s.

Nancy sees the source approaching at speed v_s.



Crest 0 was emitted at $t = 0$. The wave front is a circle centered on point 0.

The Doppler Effect

- As the wave source approaches Nancy, she detects a frequency f_+ which is slightly higher than f_0, the natural frequency of the source.
- If the source moves at a steady speed directly toward Nancy, this frequency f_+ does not change with time.
- As the wave source recedes away from Pablo, he detects a frequency f_- which is slightly lower than f_0, the natural frequency of the source.
- Again, as long as the speed of the source is constant, f_- is constant in time.

The Doppler Effect

The frequencies heard by a stationary observer when the sound source is moving at speed v_0 are:

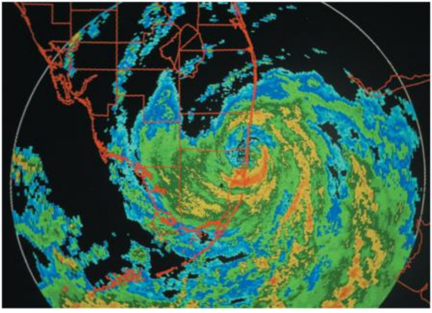
$$f_+ = \frac{f_0}{1 - v_s/v} \quad \text{(Doppler effect for an approaching source)}$$

$$f_- = \frac{f_0}{1 + v_s/v} \quad \text{(Doppler effect for a receding source)}$$

The frequencies heard by an observer moving at speed v_0 relative to a stationary sound source emitting frequency f_0 are:

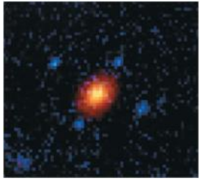
$$f_+ = (1 + v_o/v)f_0 \quad \text{(observer approaching a source)}$$

$$f_- = (1 - v_o/v)f_0 \quad \text{(observer receding from a source)}$$



Doppler weather radar uses the Doppler shift of reflected radar signals to measure wind speeds and thus better gauge the severity of a storm.

The Doppler Effect for Light Waves



- Shown is a Hubble Space Telescope picture of a *quasar.*
- Quasars are extraordinarily powerful and distant sources of light and radio waves.
- This quasar is receding away from us at more than 90% of the speed of light.
- Any receding source of light is red shifted.
- Any approaching source of light is blue shifted.

$$\lambda_- = \sqrt{\frac{1 + v_s/c}{1 - v_s/c}}\,\lambda_0 \quad \text{(receding source)}$$

$$\lambda_+ = \sqrt{\frac{1 - v_s/c}{1 + v_s/c}}\,\lambda_0 \quad \text{(approaching source)}$$