Lecture 2.7

Waves & Sound

Foundation Physics

Waves

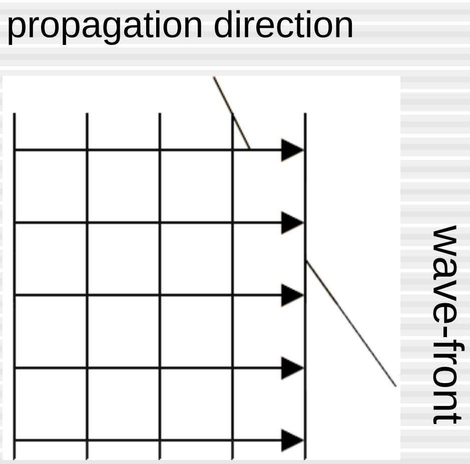
- A **wave** is a disturbance that propagates through space and time, usually with transferrance of energy. While a mechanical wave exists in a medium (which on deformation is capable of producing elastic restoring forces), waves of electromagnetic radiation (and probably gravitational radiation) can travel through vacuum, that is, without a medium. Waves travel and transfer energy from one point to another, often with little or no permanent displacement of the particles of the medium (that is, with little or no associated mass transport); instead there are oscillations around almost fixed positions.

Types of waves (1)

Example of wave	Medium	Type of perturbation
Wave on a rope	Elastic rope	Lateral motion of the rope
Wave on the surface of water	Water	Displacement from equilibrium
Sound wave	Gas, liquids, solids	Pressure changes
Electromagnetic wave (radio wave, microwave, thermal wave, light, x-rays, gamma-rays	Vacuum or matter	Electrical or magnetical fields (E-field, B-field)

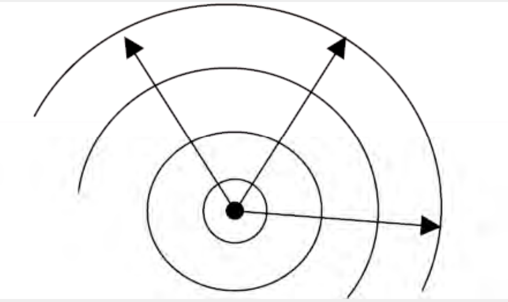
The excitation of a wave may be a vectorial or scalar quantity. (acoustic waves -> scalar, light in vacuum -> vectorial)

Types of waves (2)



Plane waves
have a propagation direction and therefore plane wave-fronts (e.g. sunlight which gets to earth, light beam of a laser)

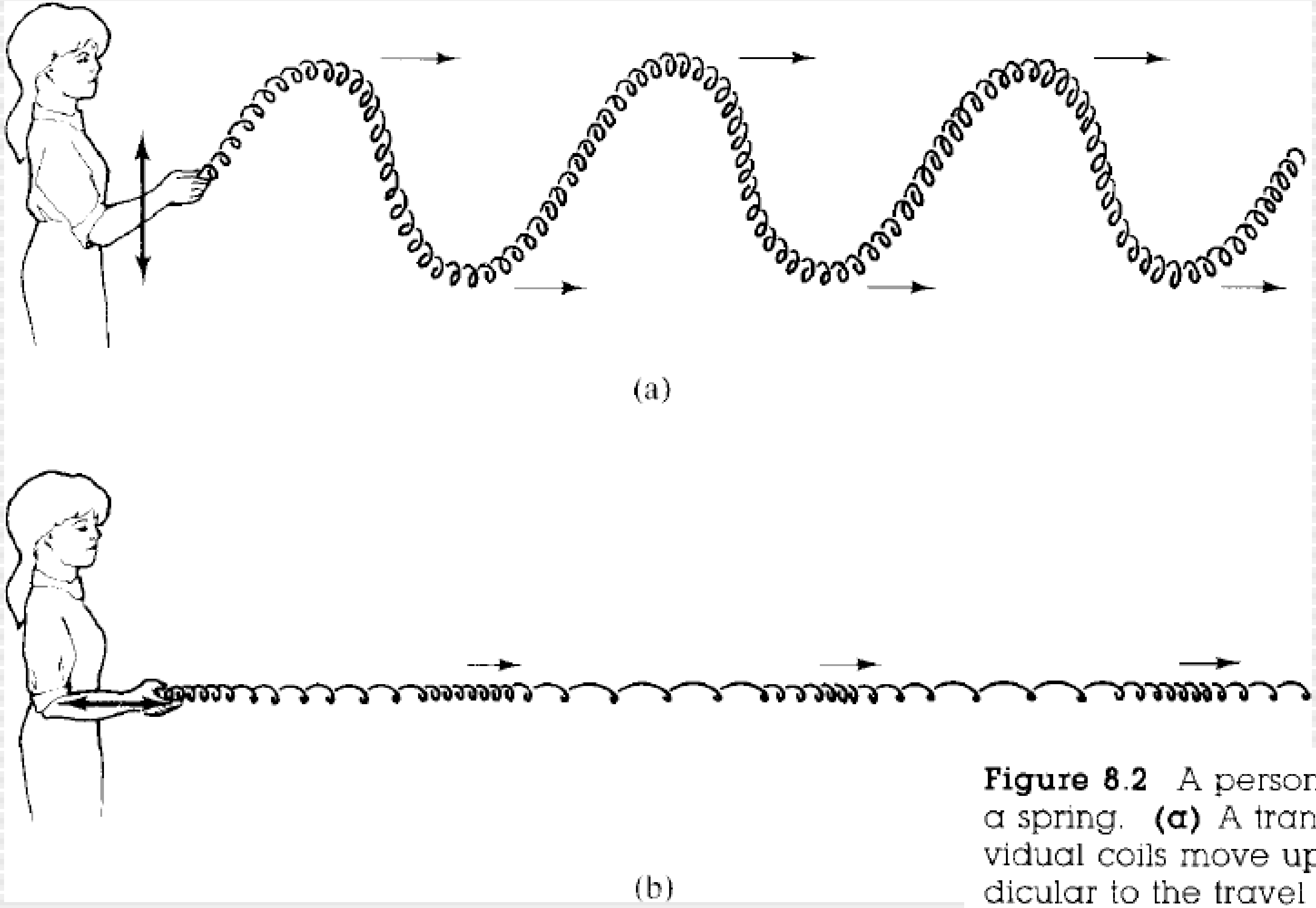
Spherical waves
Propagate radial. The wave fronts are spherical (e.g. the sound of a explosion)



Transvesal waves: Excitation longitudinal to the propagation direction (e.g. compression wave in solids)

Polarized wave: transversal wave, the excitation vector has a constant direction (e.g. polarized light)

Transvers and longitudinal waves

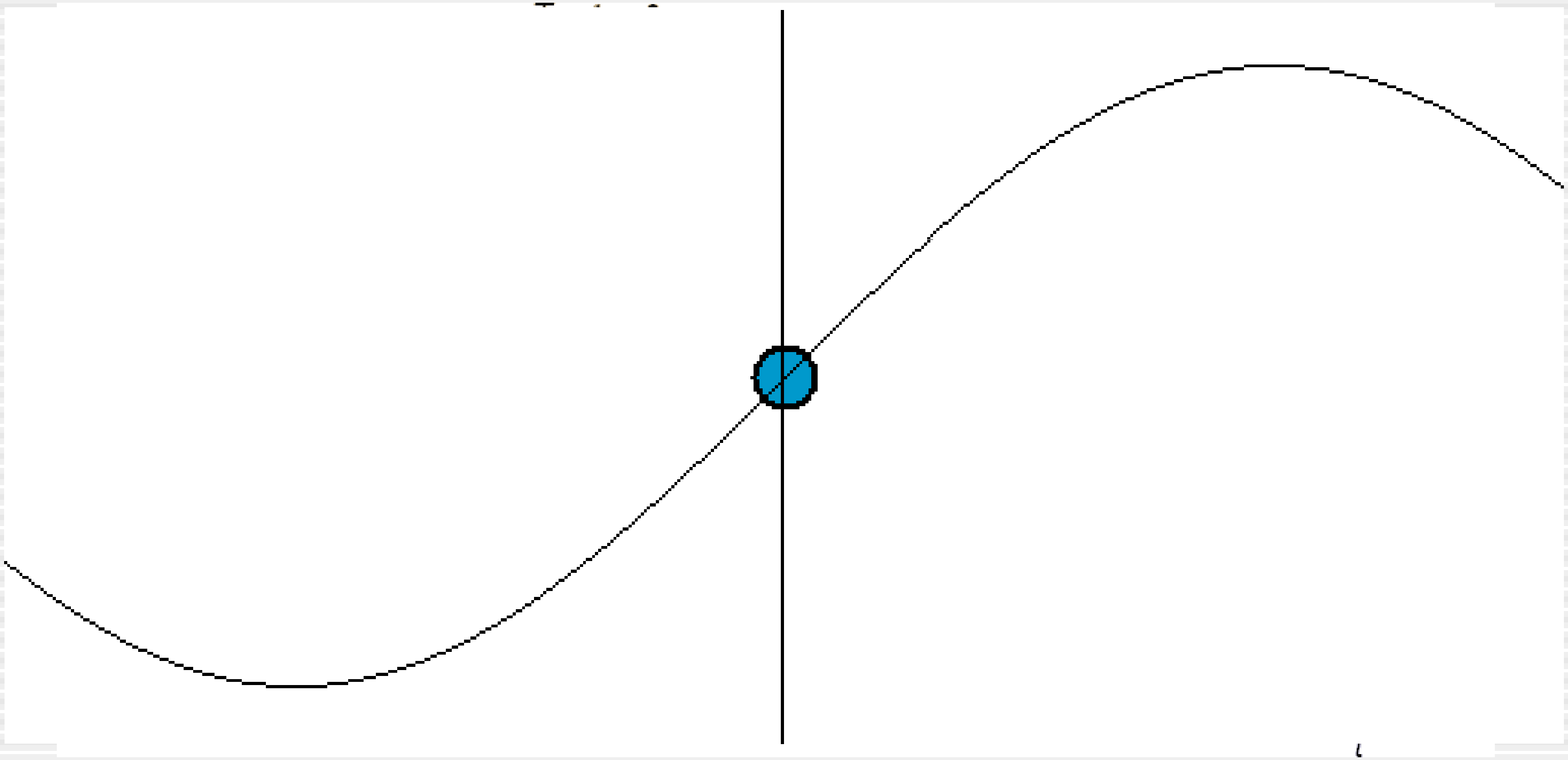


transvers

longitudinal

Figure 8.2 A person making waves on a spring. **(a)** A transverse wave; individual coils move up and down, perpendicular to the travel of the wave (to the right). **(b)** A longitudinal wave; individual coils move right and left, parallel to the travel of the wave (also to the right).

Motion of an element of a rope at position x=0

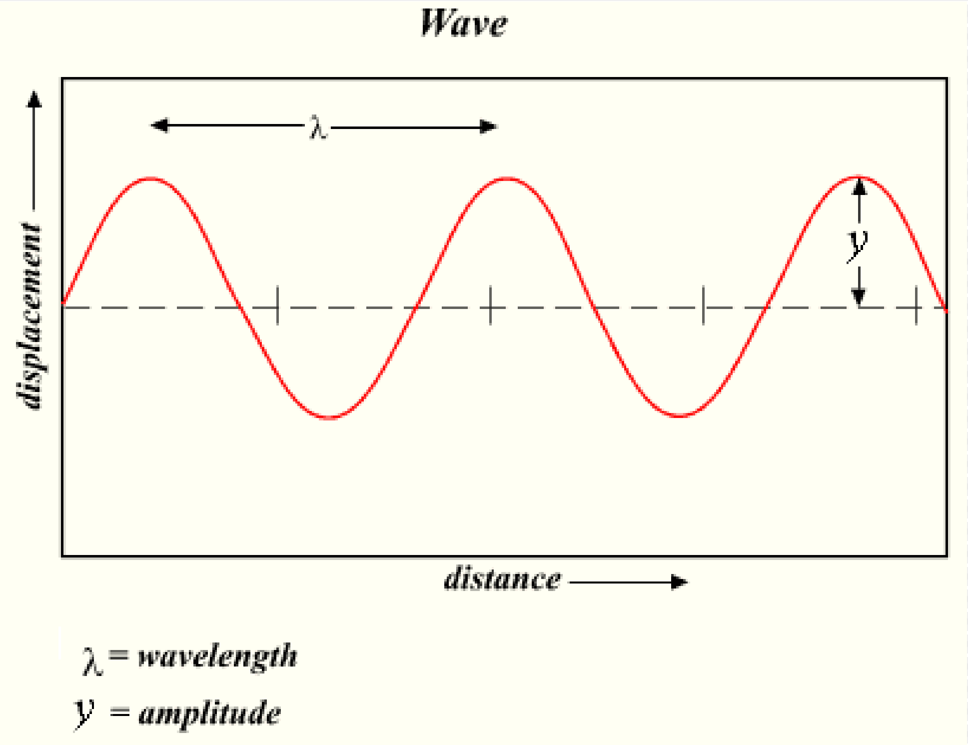


Wave

The **wavelength** (denoted as λ) is the distance between two sequential crests (or troughs). This generally has the unit of meters; it is also commonly measured in nanometers for the optical part of the electromagnetic spectrum.

A **wavenumber** *k* can be associated with the wavelength by the relation

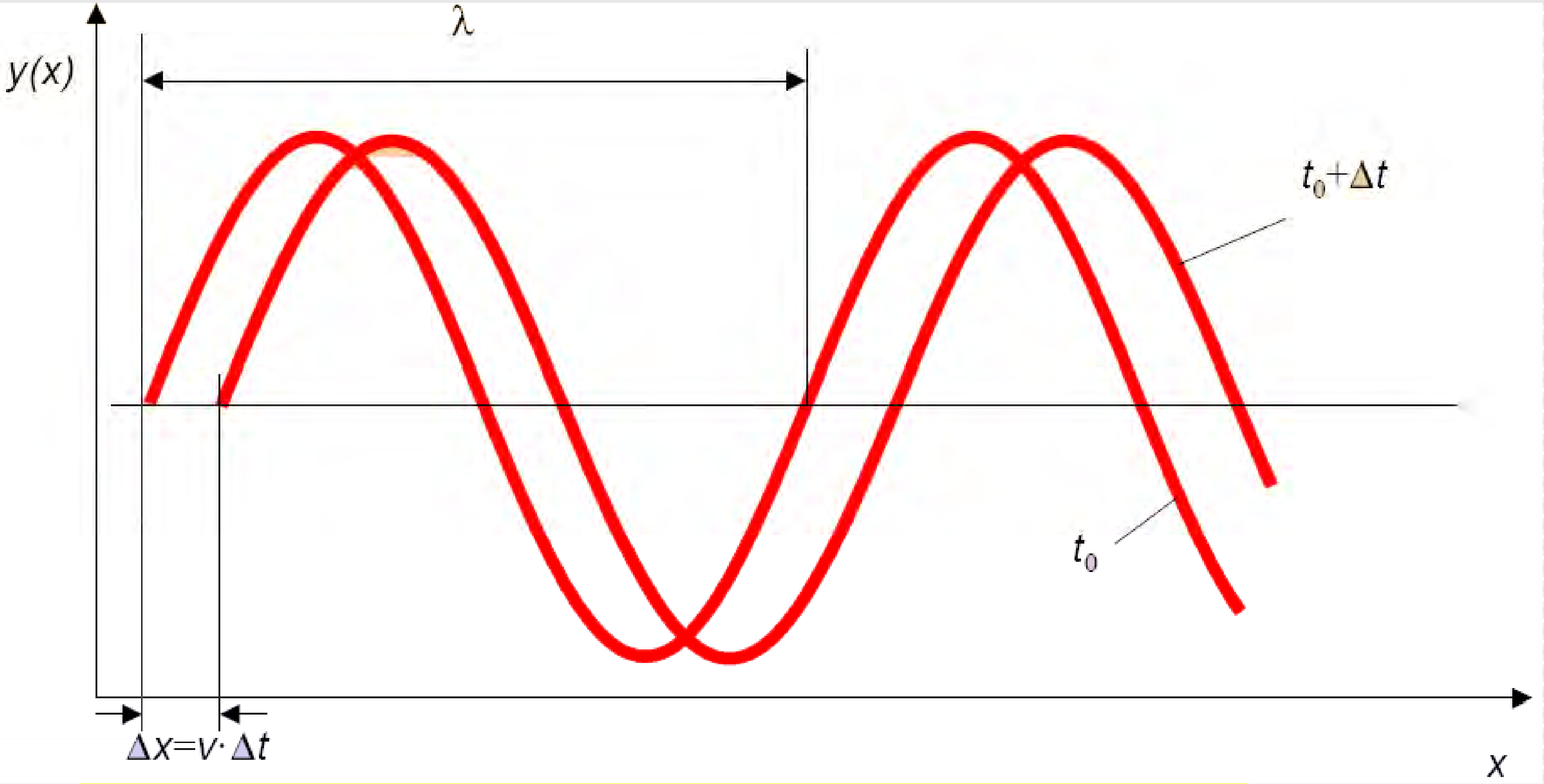
$$k = \frac{2 \cdot \pi}{\lambda}$$



$$f = \frac{1}{T}$$

$$c = f \cdot \lambda$$

Snapshot of the harmonic wave at time $t=t_0$ and $t=t_0+\Delta t$

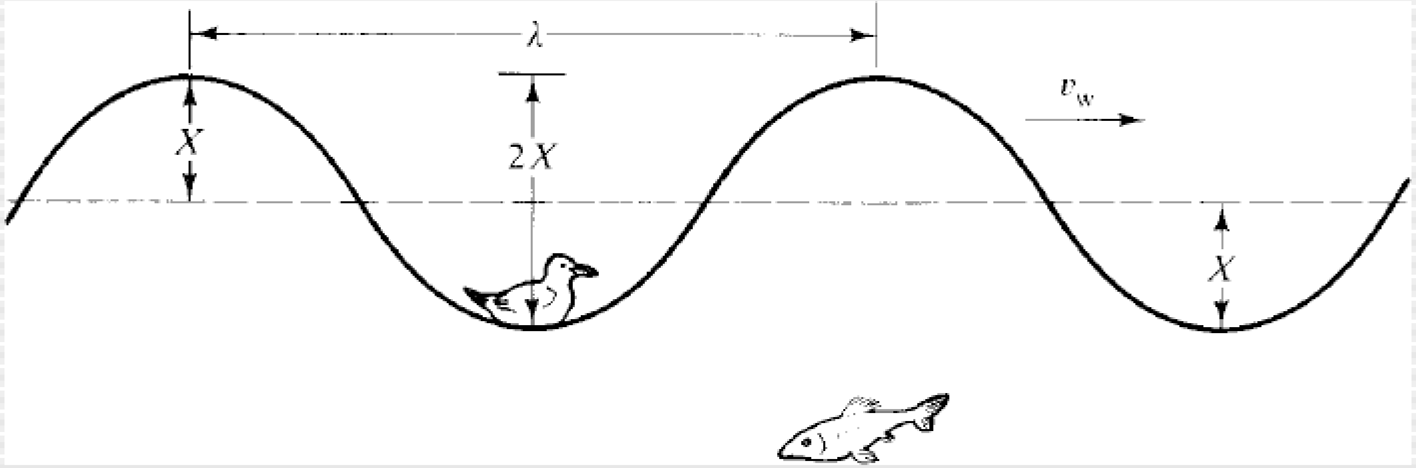


if $\Delta t = T$: $\Delta x = \lambda = v \cdot T$

$\mathrm{v_w} = \lambda \cdot f$ $\mathrm{v_w}$: speed of propagation

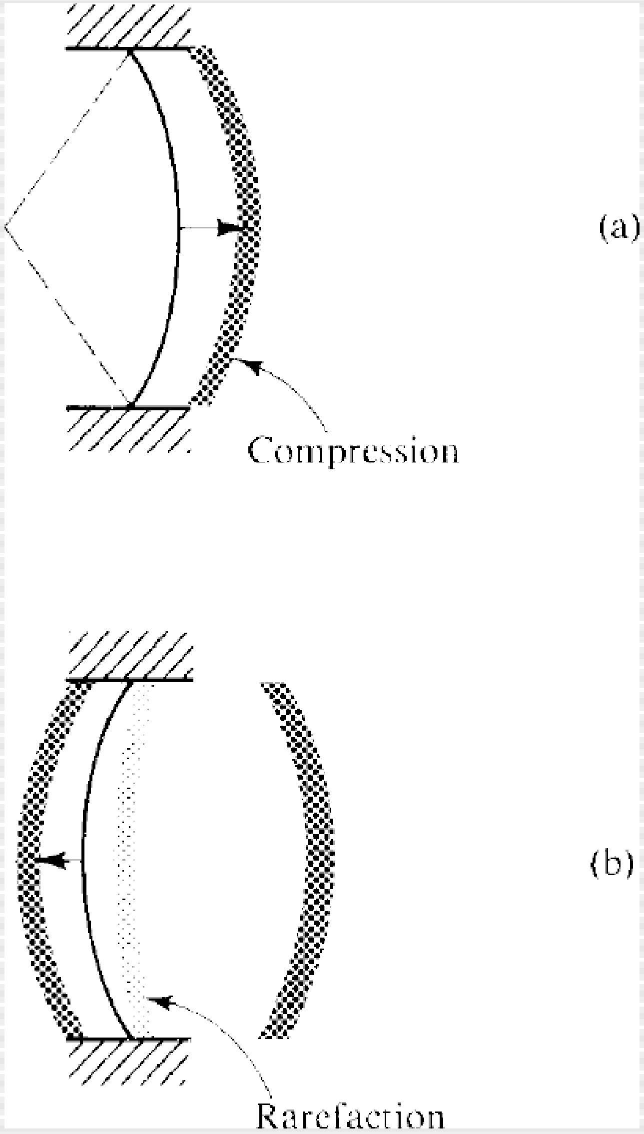
Example

Calculate the speed of propagation of the ocean wave in figure below if its crests are 20m apart and the bird takes 8.0 sec to complete one trip up and down?



$$v_w = \lambda/T = 20\text{ m}/8.0\text{ sec} = 2.5\text{ m/sec}$$

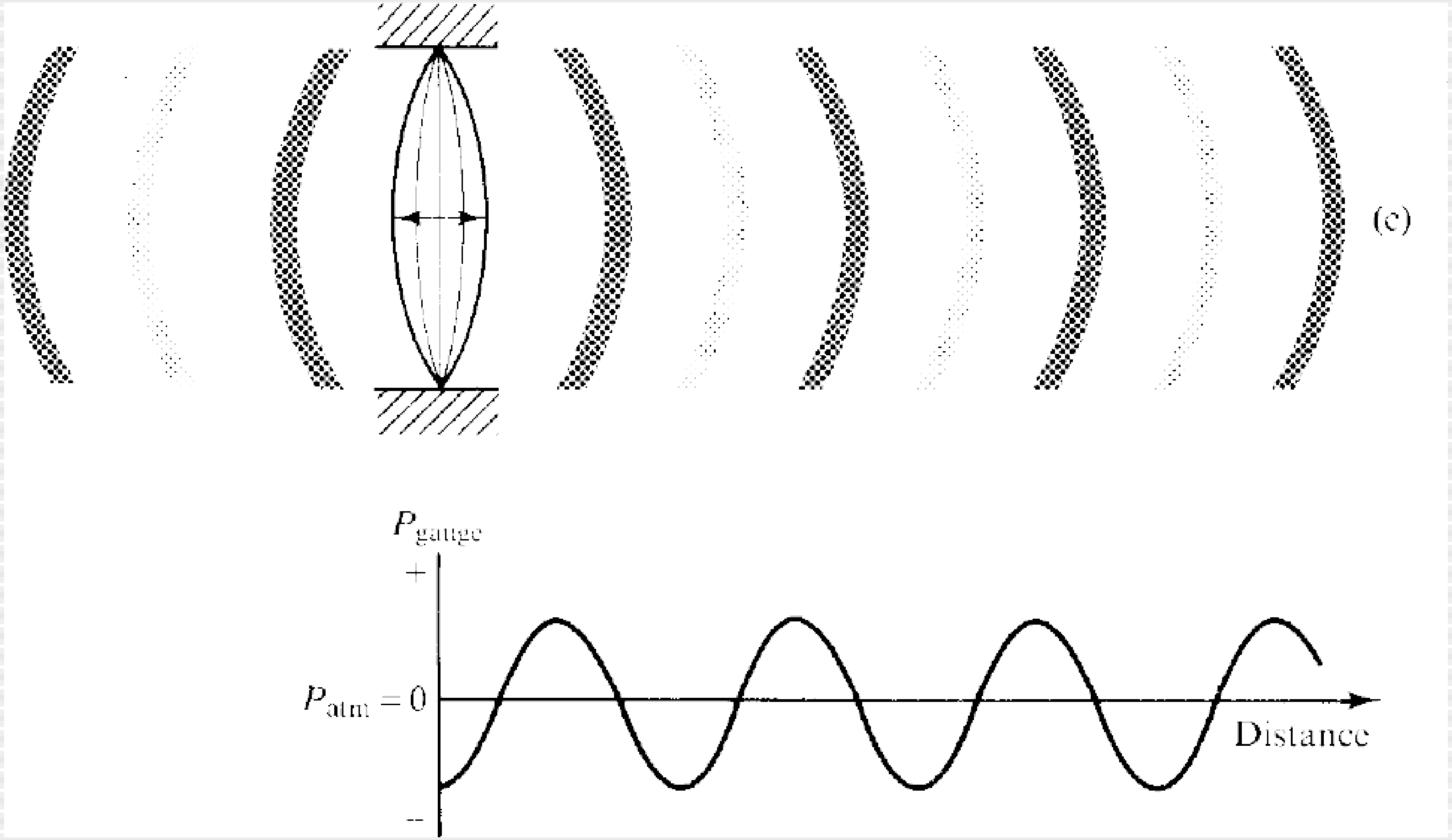
Sound wave created by a string



Sound waves created by a vibrating string (a) A compression being made by the string moving to the right. The dotted line shows deformation of the string moving to the right when it was released

(b) A rarefaction being made by the string moving to the left. The ealier compression has moved to the right.

Repeated motion sends out periodic sound waves



Sound

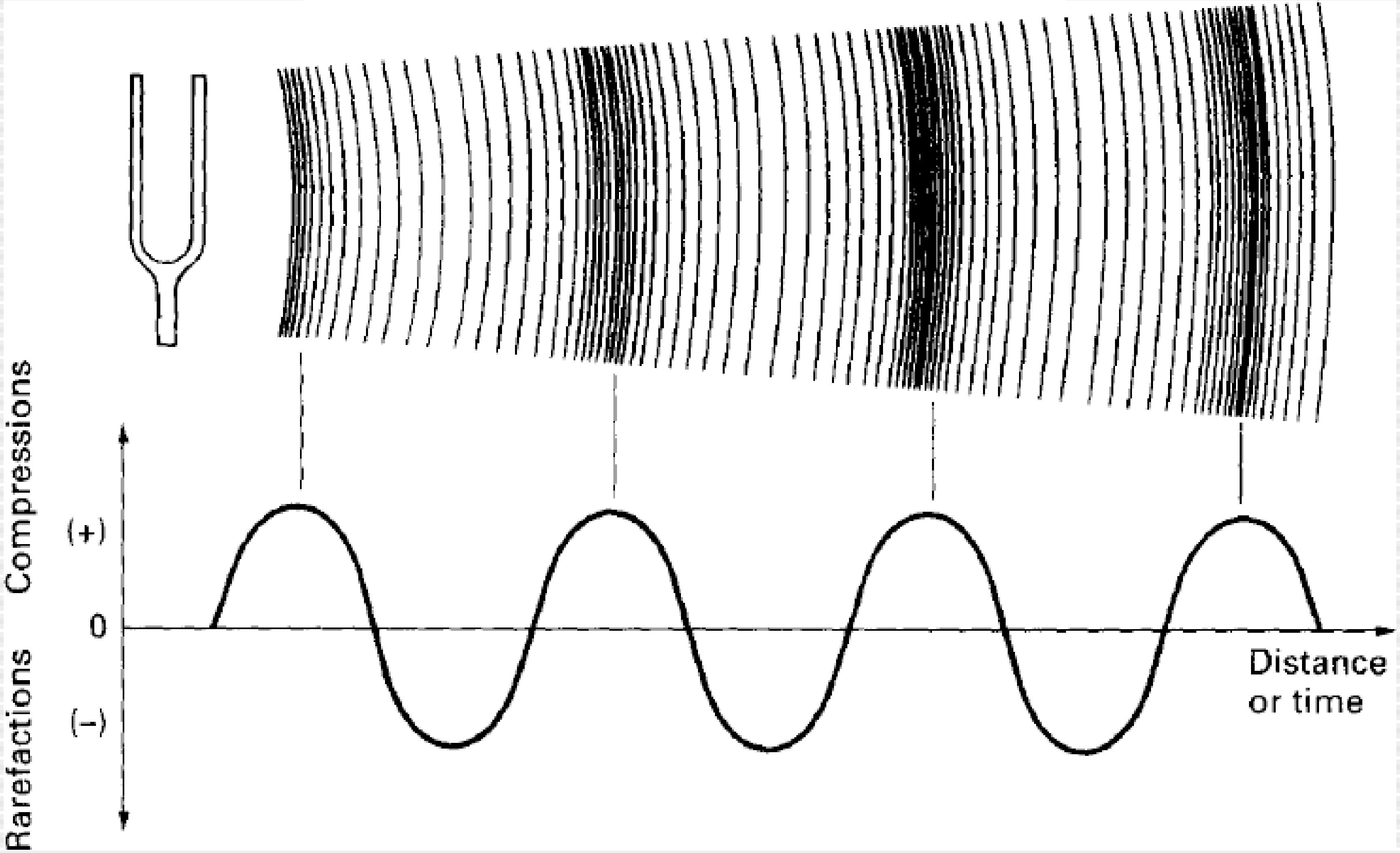
All matter transmits sound to some extent, but a material medium is needed between the source and the receiver to propagate sound. This is demonstrated by the well-known experiment of the bell in the jar. When the bell is set in motion, its sound is clearly audible. As the air is evacuated from the jar, the sound of the bell diminishes and finally the bell becomes inaudible.

Sound (II)

The propagating disturbance in the sound-conducting medium is in the form of alternate compressions and rarefactions of the medium, which are initially caused by the vibrating sound source. These compressions and rarefactions are simply deviations in the density of the medium from the average value. In a gas, the variations in density are equivalent to pressure changes.

$$\boxed{P = F / A} \qquad [N / m^2]$$

Waves can cause objects to vibrate



Pressure of sound

The pressure variations due to the propagating sound are superimposed on the ambient air pressure. Thus, the total pressure in the path of a sinusoidal sound wave is of the form

$$P = P_a + P_0 \sin \cdot 2 \cdot \pi \cdot f \cdot t$$

P_a is the ambient air pressure (which at sea level at O^{o}C is 1.01 x 10^5Pa, P_o is the maximum pressure change due to the sound wave, and *f* is the frequency of the sound.

Intensity of Sound

The amount of energy transmitted by a sinusoidal sound wave per unit time through each unit area perpendicular to the direction of sound propagation is called the intensity *I* and is given by

$$I = \frac{P_0^{\,2}}{2 \cdot \rho \cdot \mathrm{v}}$$

Here ρ is the density of the medium, and v is the speed of sound propagation.

$$I = \frac{E/t}{\mathrm{A}} = \frac{P}{A} \qquad [W/m^2]$$

Intensity of sound

Sound intensity level, L_I, is the magnitude of sound intensity, expressed in logarithmic units (decibels).

$$L_I = 10 \cdot \log 10 \frac{|I|}{I_0}$$

where I_o is the reference intensity, 10^{-12} W/m^2

Sound intensity

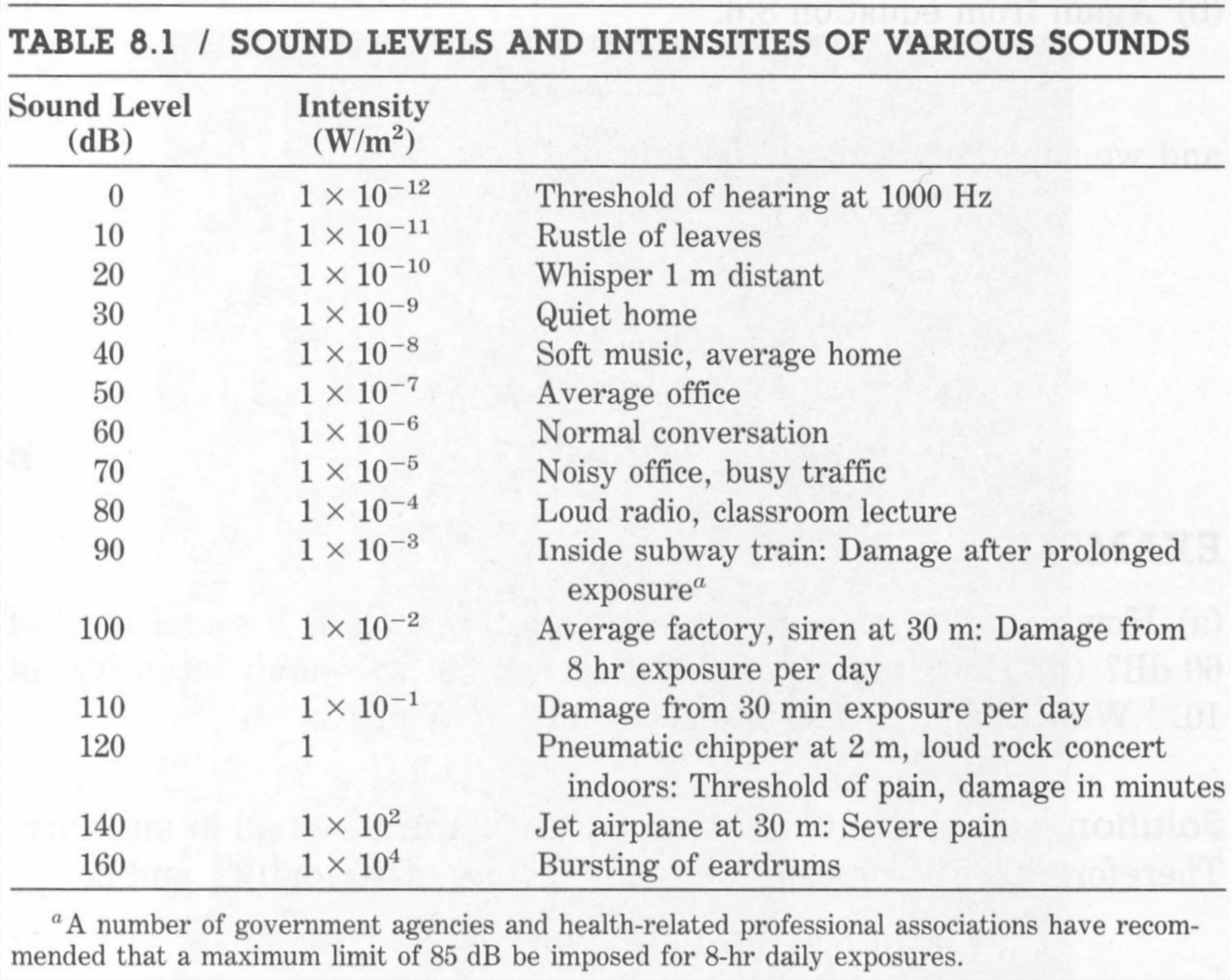


TABLE 8.1 / SOUND LEVELS AND INTENSITIES OF VARIOUS SOUNDS

Sound Level (dB)	Intensity (W/m^2)	
0	1×10^{-12}	Threshold of hearing at 1000 Hz
10	1×10^{-11}	Rustle of leaves
20	1×10^{-10}	Whisper 1 m distant
30	1×10^{-9}	Quiet home
40	1×10^{-8}	Soft music, average home
50	1×10^{-7}	Average office
60	1×10^{-6}	Normal conversation
70	1×10^{-5}	Noisy office, busy traffic
80	1×10^{-4}	Loud radio, classroom lecture
90	1×10^{-3}	Inside subway train: Damage after prolonged exposure[a]
100	1×10^{-2}	Average factory, siren at 30 m: Damage from 8 hr exposure per day
110	1×10^{-1}	Damage from 30 min exposure per day
120	1	Pneumatic chipper at 2 m, loud rock concert indoors: Threshold of pain, damage in minutes
140	1×10^{2}	Jet airplane at 30 m: Severe pain
160	1×10^{4}	Bursting of eardrums

[a] A number of government agencies and health-related professional associations have recommended that a maximum limit of 85 dB be imposed for 8-hr daily exposures.

Speed of propagation of sound

Media	**Propagation speed of sound (m/s)**
CO_2	226
N_2	349
Dry air (20C)	343
Dry air (0C)	331
He	1007
H_2	1309
Lead	1300
Water	1485
Aluminium	5100
Glass	5400
Beryllium	12900
Diamond	17500

Wave length in different media

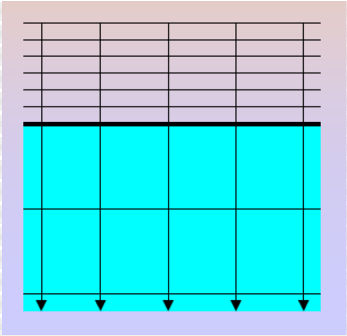
The frequency *f* of a wave is defined by the source. But the wave length λ is depending on the propagation speed (and therefore on the media)

$$\mathrm{v} = \lambda \cdot f \Rightarrow \lambda = \mathrm{v} / f$$

Example: A sound wave ith a frequency *f*=1000Hz is propagating through air and hits a air-water interface. What is the wavelength in air and what the wave length in water (λ_{air},, λ_{water})?

$$\lambda_{air} = \frac{\mathrm{v}_{(air)}}{f} = \frac{343}{1000} = 0.34\mathrm{m}$$

$$\lambda_{water} = \frac{\mathrm{v}_{(water)}}{f} = \frac{1485}{1000} = 1.485\mathrm{m}$$



Next Lecture

- To Be Covered: Sound
- Reading: Chapter 8
  - Section 8.4 Wave superposition and resonance