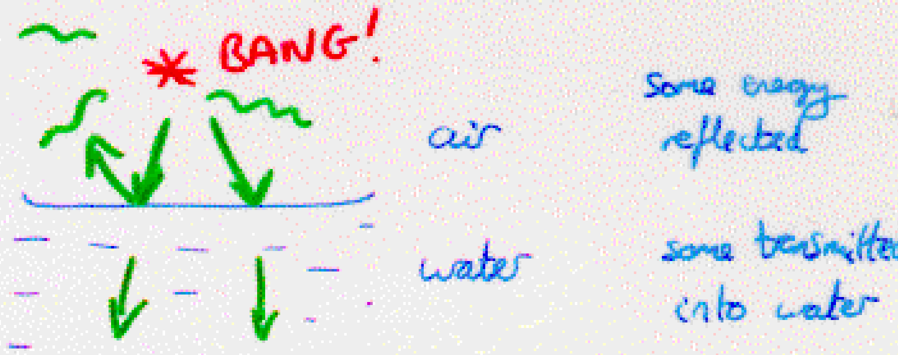
Sound Waves (Acoustics)

General Wave Properties

- Absorption - oscillation can be damped ⇒ dissipates energy
- Reflection - when wave hits discontinuity in medium (e.g. echoes, sonar, ultrasound imaging)

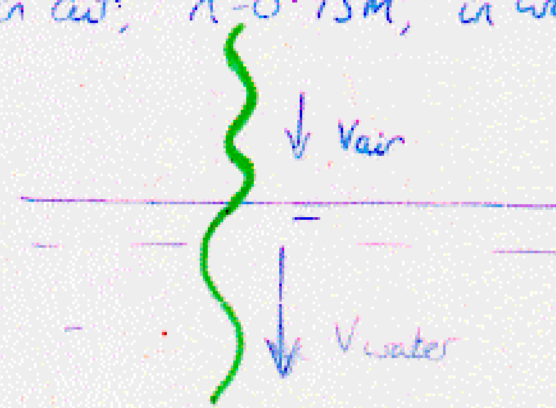
- Transmission - wave energy transfers into another medium.

e.g.



Note: Wave frequency f is the same in any medium (so we hear the same "note"), so if speed v changes, wavelength $\lambda = \frac{v}{f}$ changes

e.g. $f = 440\,Hz$: in air, $\lambda = 0.75m$, in water: $\lambda = 2.25m$



Sound as a Compression Wave

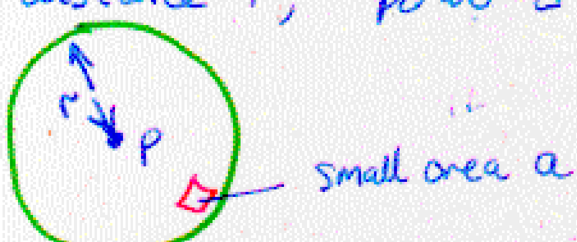
Speaker vibrates
$\Rightarrow$ air molecules displaced along direction of wave

For typical sounds, amplitude $A \sim$ few mm, related to energy of wave (not wavelength λ).

For harmonic waves, molecules execute SHM with $E \propto A^2$ (c.f. mass on spring)
so wave energy $\propto A^2$

Sound Intensity:

If sound wave expands from a source of power P [W]
At distance r, power is spread over sphere area $4\pi r^2$:



Define Intensity = Power/Area i.e. $\boxed{I = \dfrac{P}{4\pi r^2}}$

e.g. For 100W speaker, how much power impinges on ear (area $\sim 5 \times 10^{-4}\,m^2$) at (a) 5m, (b) 50m ?

Figure 11.21
Waves from a loudspeaker

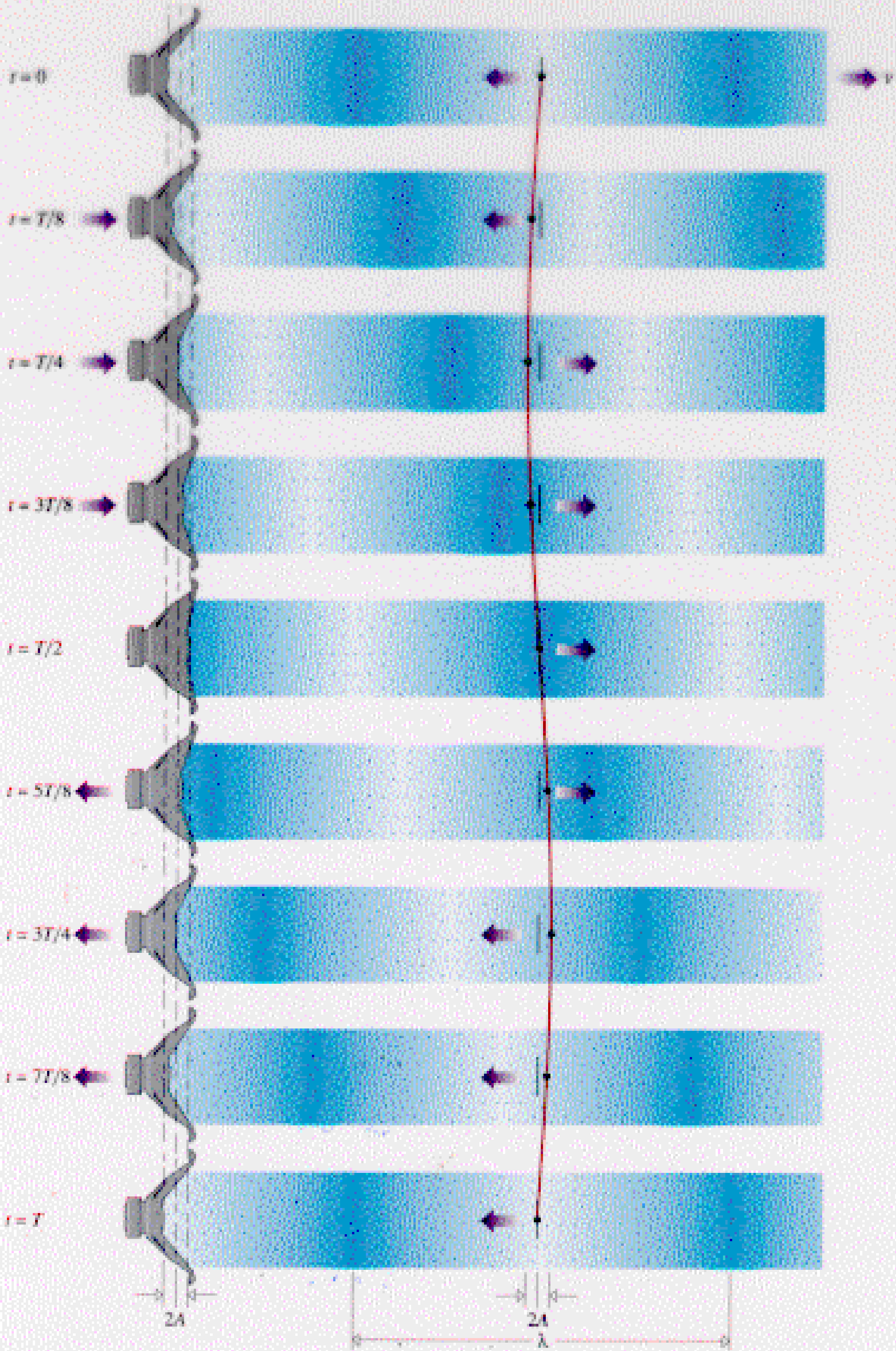


Figure 11.22

Sinusoidal sound wave

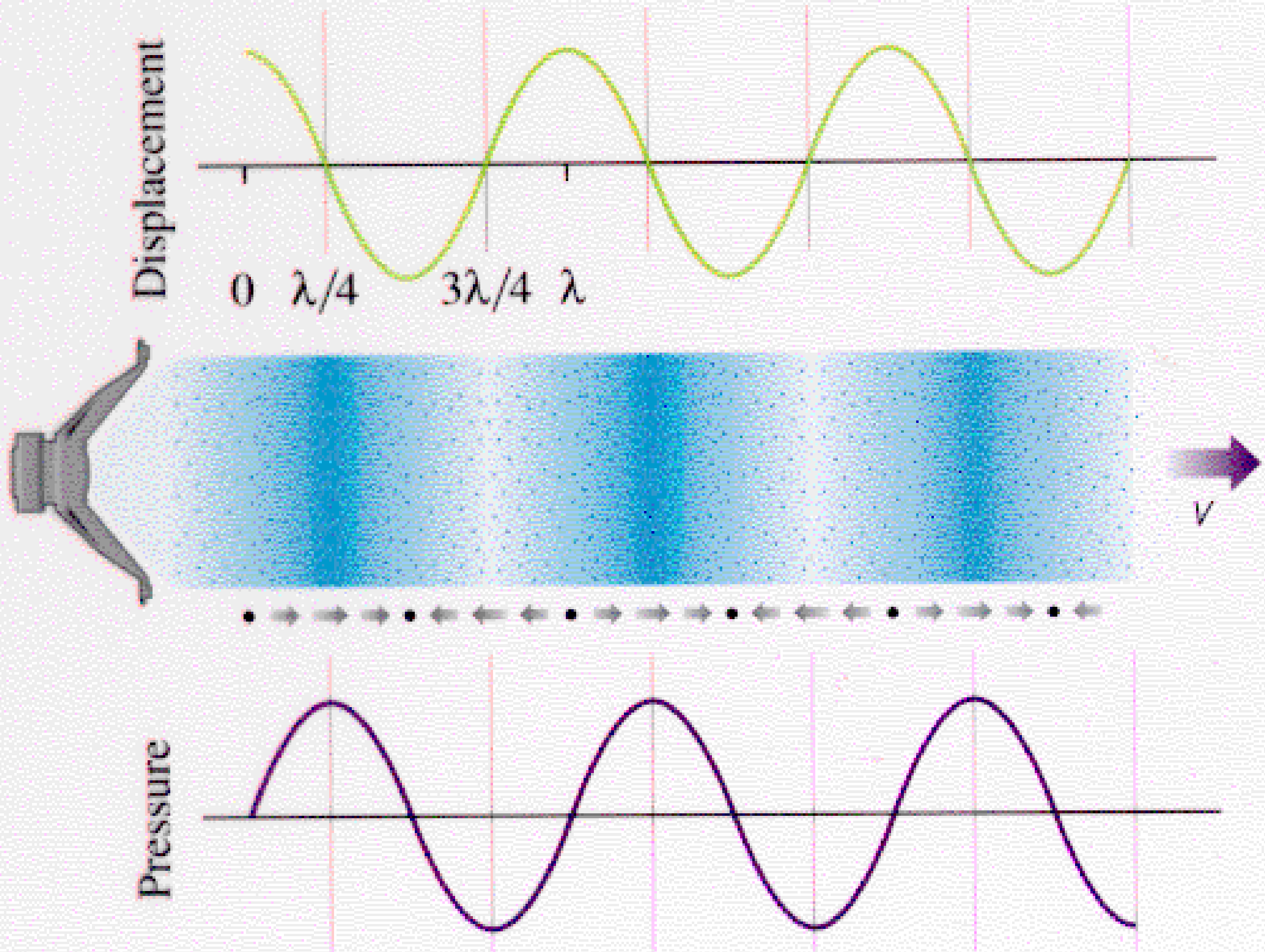
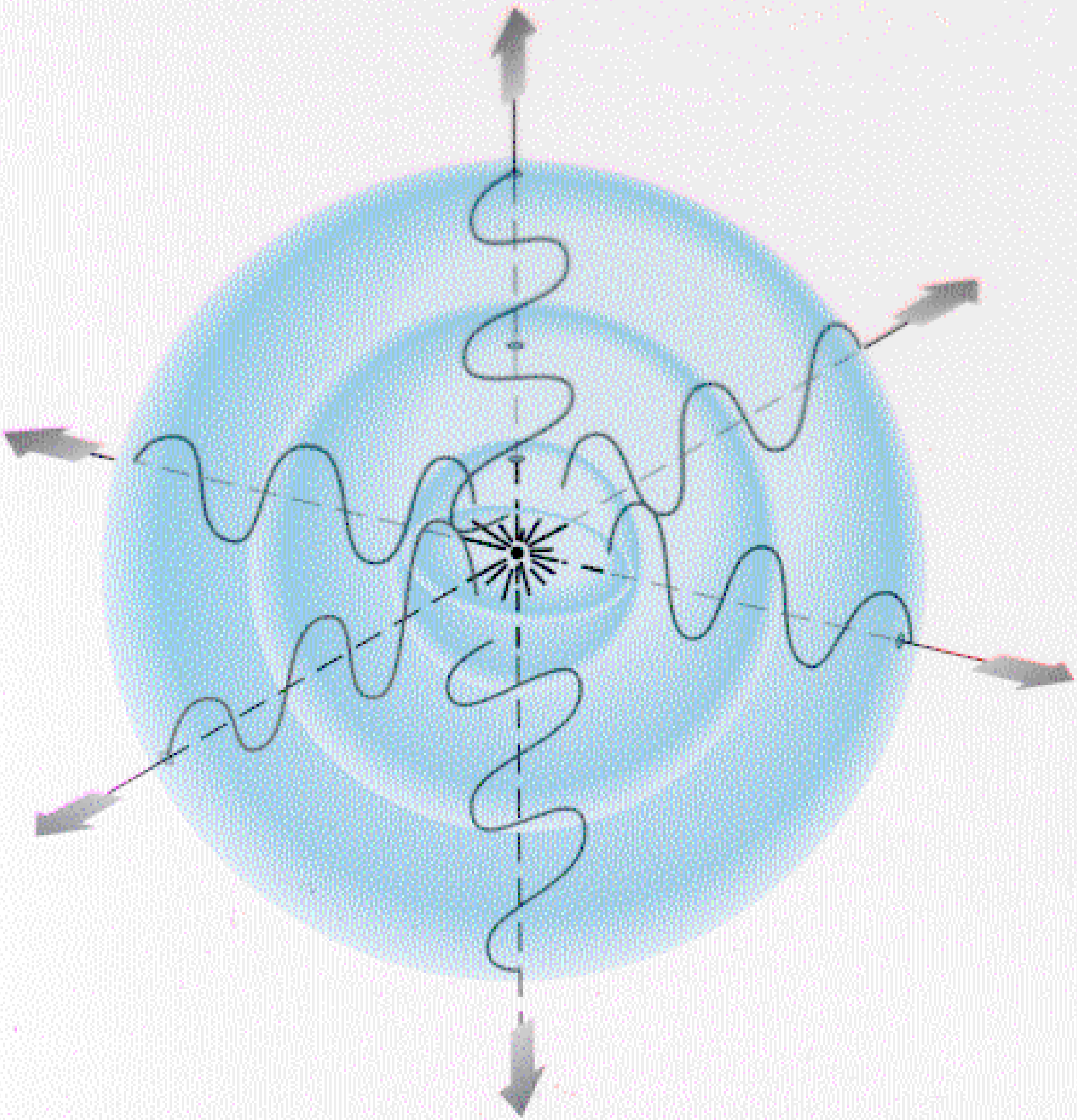


Figure 11.32

Wave from a point source



Superposition of Waves

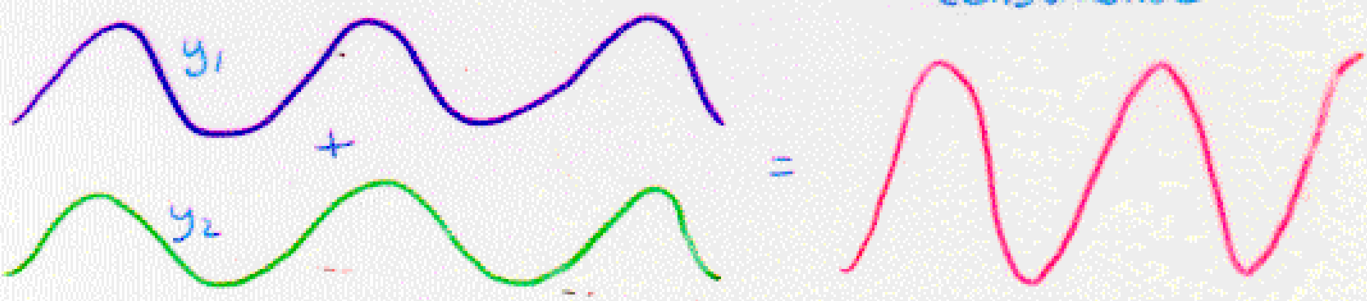
When 2 waves in medium meet, resulting displacement $y(x,t) = y_1(x,t) + y_2(x,t)$

– just add them, no "collision" or energy/momentum transfer between waves.

We say waves INTERFERE.

"constructive"

in phase

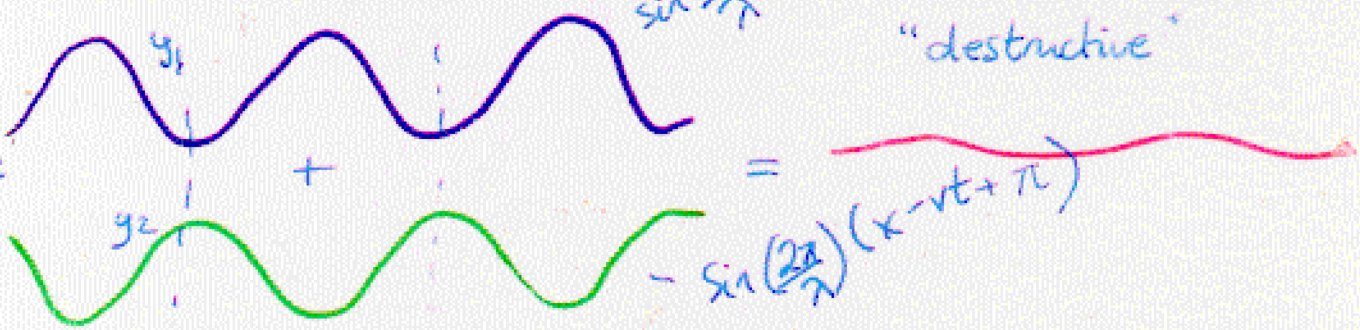


OR

$\sin\frac{2\pi}{\lambda}(x-vt)$

"destructive"

out of phase



$-\sin\left(\frac{2\pi}{\lambda}\right)(x-vt+\pi)$

Interference is a purely wave phenomenon: two energetic waves can "cancel out" to give ~ nothing!

(Waves are non-local – energy is conserved overall but not at specific locations.)

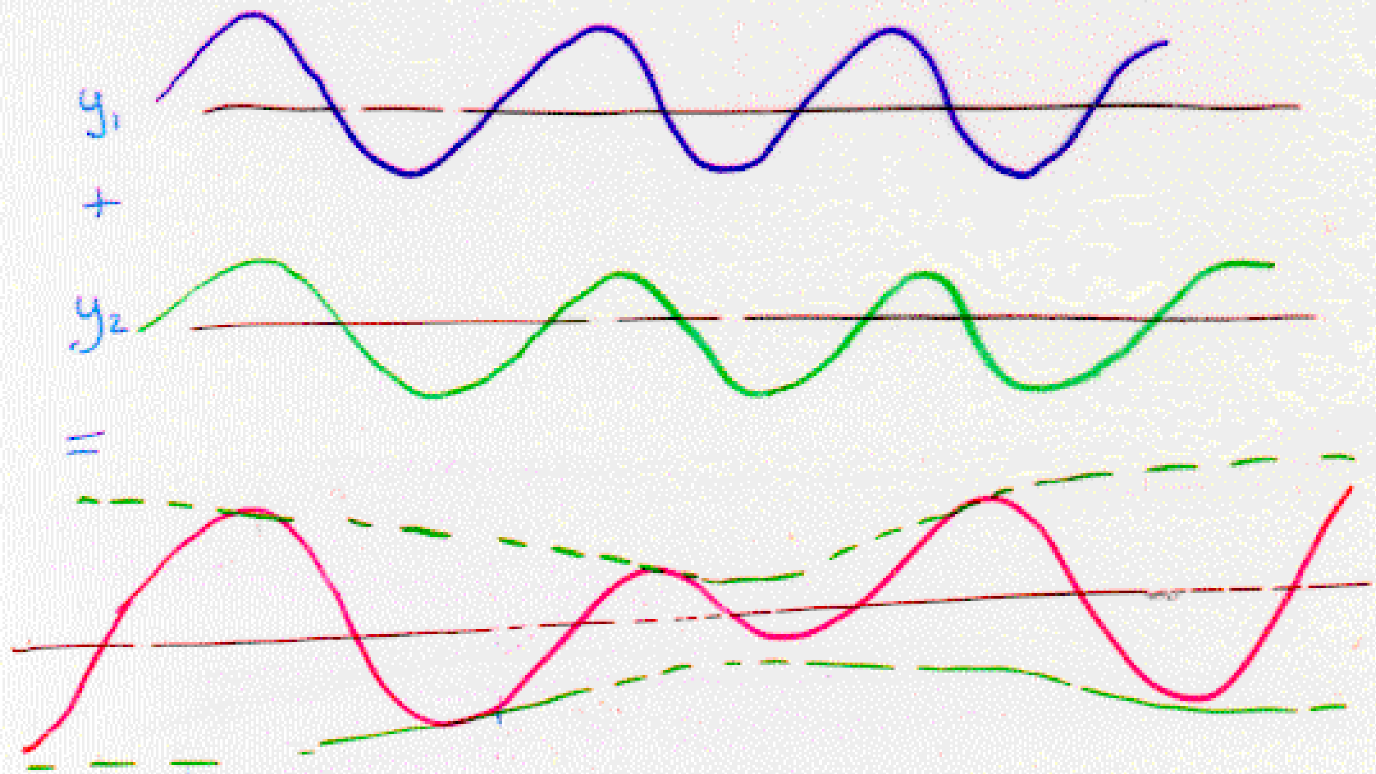
Interference Effects : Beats

If 2 waves differ slightly in freq. f:

At $x=0$: $y = y_1 + y_2 = A\cos 2\pi f_1 t + A\cos 2\pi f_2 t$

[Use $\cos\theta + \cos\phi = 2\sin\left(\frac{\phi+\theta}{2}\right)\cos\left(\frac{\phi-\theta}{2}\right)$]

$\Rightarrow y = 2A\sin 2\pi\left(\frac{f_1+f_2}{2}\right)t \cos 2\pi\left(\frac{f_1-f_2}{2}\right)t$



Resulting wave has average freq. $= \frac{f_1+f_2}{2}$ and

amplitude $= 2A\cos 2\pi\left(\frac{f_1-f_2}{2}\right)t$

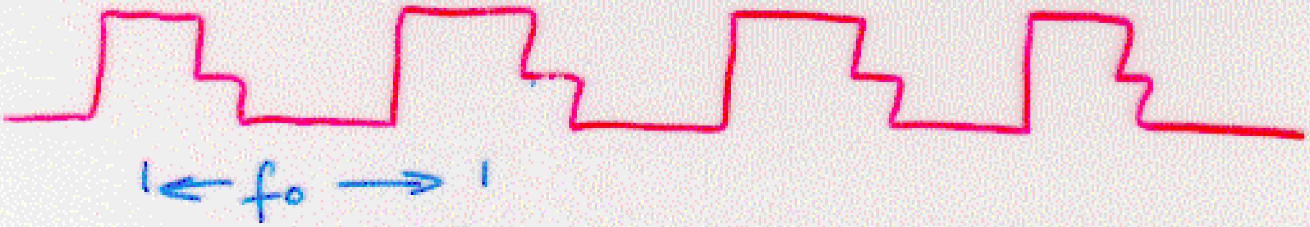
– grows + declines at frequency $f_{beat} = f_1 - f_2$

Used to tune instruments. As $f_2 \to f_1$, beat interval

$t_{beat} = \frac{1}{f_1 - f_2}$ increases.

Superposition cont/d : Fourier Synthesis

Every periodic wave has fundamental (lowest) freq. f_0



Fourier (1807) showed: Any periodic waveform can be synthesized by adding harmonic waves together with frequencies f_0, $2f_0$, $3f_0$, $4f_0$, $5f_0$, ...
by choosing correct amplitudes and phases

e.g. Fig. 11·28, or:

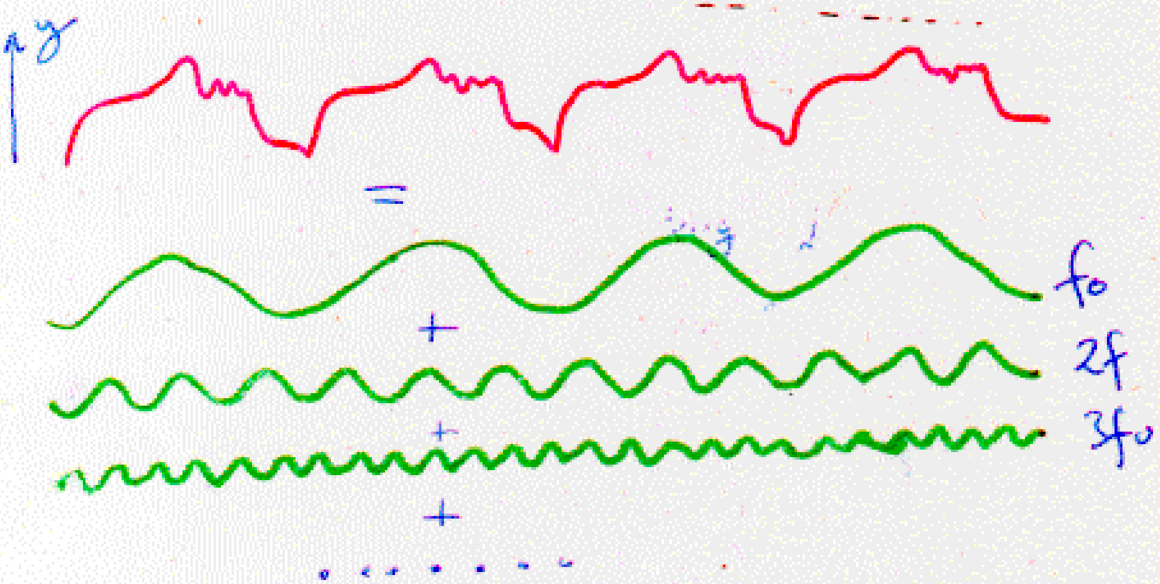
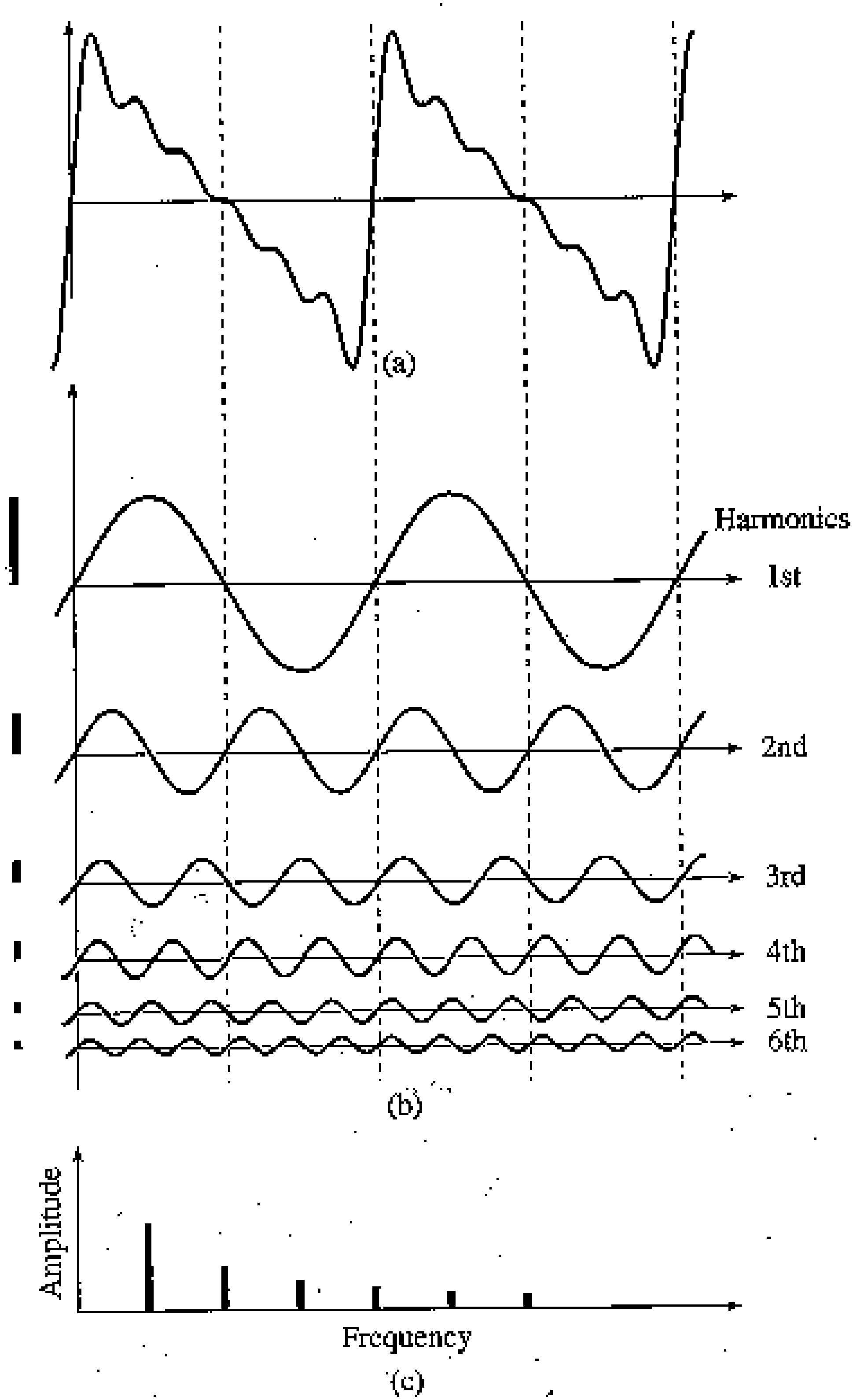


Figure 11.28

Synthesis of a sawtooth wave



Basic Properties of a Continuous Sound Wave

(e.g. musical note, vowel in speech)

- Intensity ("loudness") = power / unit area

$$\propto [\text{amplitude}]^2$$

$$\propto \frac{1}{[\text{distance}]^2}$$

- Pitch = freq. of fundamental tone f_0

(Why not give λ? (i) λ depends on the medium $\lambda = v/f$

(ii) ears measure frequency, not λ).

- 'Timbre' = the particular superposition of harmonics $2f_0$, $3f_0$, ... required to produce the waveform.

So $f = 440$ Hz on piano sound different to $f = 440$ Hz on flute, violin etc.

Figure 11.35

Frequency ranges of voices and instruments