Standing waves → open end ?

We derived standing-wave conditions for a string fixed at both ends :

1) left- and right-travelling sinusoidal waves of arbitrary frequency were added → standing wave

2) node-conditions were imposed at $x = 0$ and $x = L$.

Quantization of modes : $\lambda_n = \frac{2L}{n}$, $f_n = \frac{c}{\lambda_n}$ ← v_w

$n = 1, 2, 3, \ldots$

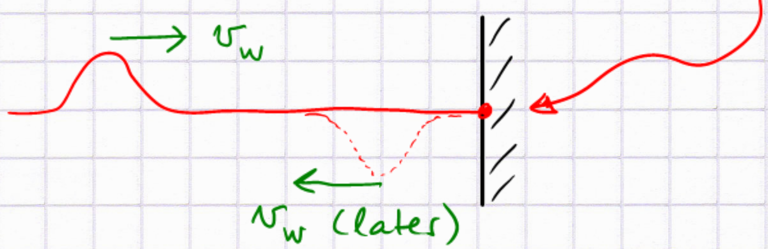
f_1 = fundamental ; $f_2 = 2^{nd}$ overtone, etc.

Is this the only option ? Can one end be open ?

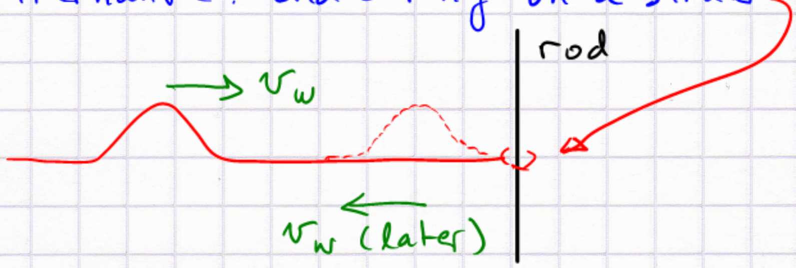
→ Happens in wind instruments (end usually open, but can be "closed" → change in frequency)

→ Back to sending pulses on a rope :

Fig 12.17 : end is fixed, pulse reflects (changes sign)



Alternative : end = ring on a slider, slides up/down when pulse arrives



RHS : not a node, but an antinode.

Add counterpropagating waves for this boundary : Chapter 13.3 → details for sound

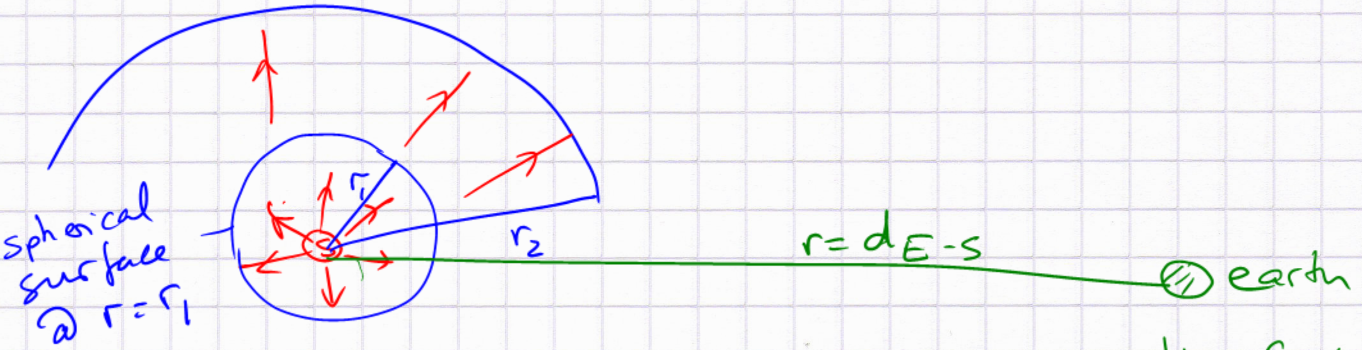
longitudinal ! →

Waves : Intensity = Power delivered to area,

i.e., Power/Area

Consider a point source in 3d:

e.g., sun emits thermal radiation → thermal EM, visible EM, ultraviolet



- all power passes through this surface ($A = 4\pi r_1^2$)

a tiny fraction of sun's radiation illuminates earth

- the same total power passes through surface of $r = r_2$
- " " " " " " " $r = d_{ES}$

A tiny fraction of this power reaches the earth's surface

Intensity (unit $= \frac{\text{Watt}}{m^2}$) is $\frac{\text{power}}{\text{area}} = \frac{P}{4\pi r^2}$

is falling off $\sim \frac{1}{r^2}$ → purely geometrical argument

earth picks up a tiny fraction, since its surface area is tiny compared to $4\pi d_{E-S}^2$.

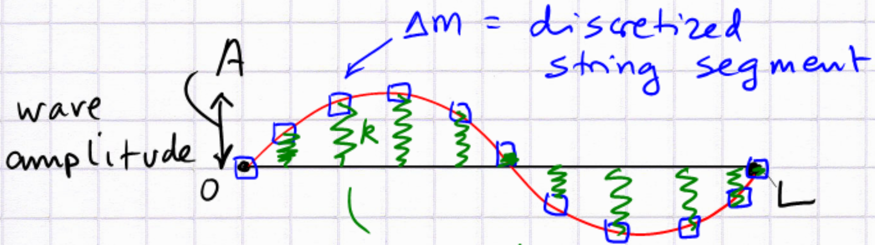
Another example: 60 W lightbulb in desk lamp illuminates our textbook. Vary lamp – book distance

→ brightness change

Wave intensity ~ amplitude squared $I \sim A^2$

Plausibility argument: transverse wave on a string

mass segments Δm are vertical harmonic oscillators



spring-like restoring forces pull Δm towards equilibrium

Energy associated with transverse motion:

$PE_{max} \sim \frac{1}{2} k A^2$ $KE_{max} = \frac{1}{2} \Delta m \left(v_y^{max}\right)^2$

$\text{Power} = \frac{\text{Energy}}{\text{Time}} \Rightarrow \text{Wave intensity} = \frac{P}{\text{area}} \sim A^2$

Interesting: v_y^{max} has nothing to do with $v_w = c$ = wave propagation speed!

$$D(x,t) = A \sin\left(\frac{2\pi t}{T} - \frac{2\pi x}{\lambda}\right) \qquad v_w = \frac{\lambda}{T}$$

but

$$v_y(x,t) = \underbrace{\frac{\partial}{\partial t}}_{x \text{ is "constant"}} D(x,t) = A \cos\left(\frac{2\pi t}{T} - \frac{2\pi x}{\lambda}\right)\left(\frac{2\pi}{T}\right)$$

$$v_y^{max} = \frac{2\pi A}{T} = A\omega$$

wave intensity $\left(\frac{\text{power}}{\text{area}}\right)$ is controlled by transverse (local) motion.

There is an independent (often much higher-velocity) energy scale associated with wave propagation.

E&M: wave guides photons moving with $v = c$

A controls how many photons/second; Photon energy: $E = hf$ Planck