Musical Acoustics

Lecture 8

Waves - 3

Intensity

Intensity: rate of energy flow through an area

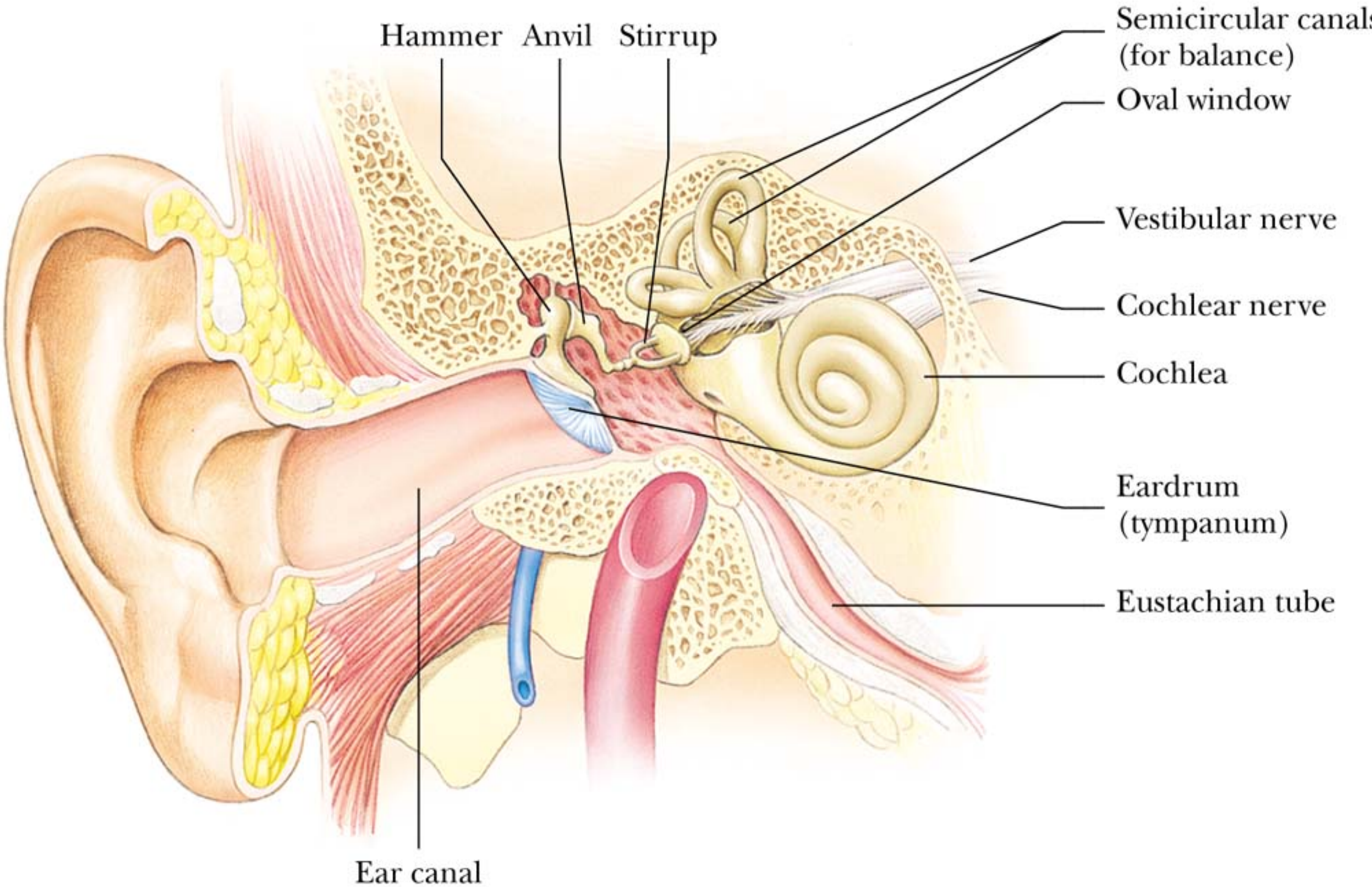
Power (P) J/s

A (m^2)

$$I = P/A \quad (J/m^2s = W/m^2)$$

Example: If you buy a speaker, it *gives* power output in Watts. However, even if you put a powerful speaker in a large room, the intensity of the sound can be small.

Intensity



- **Faintest sound** we can hear: I ~ 1×10^{-12} W/m^2 (at 1000 Hz)
- **Loudest sound** we can stand: I ~ 1 W/m^2 (at 1000 Hz)

Factor of 10^{12}? Loudness works **logarithmic**…

Logarithms

Index
Power
Exponent
<u>Logarithm</u>

Base $\rightarrow$ $10^2 = 100$ $\leftarrow$ Number

"10 raised to the power 2 gives 100"

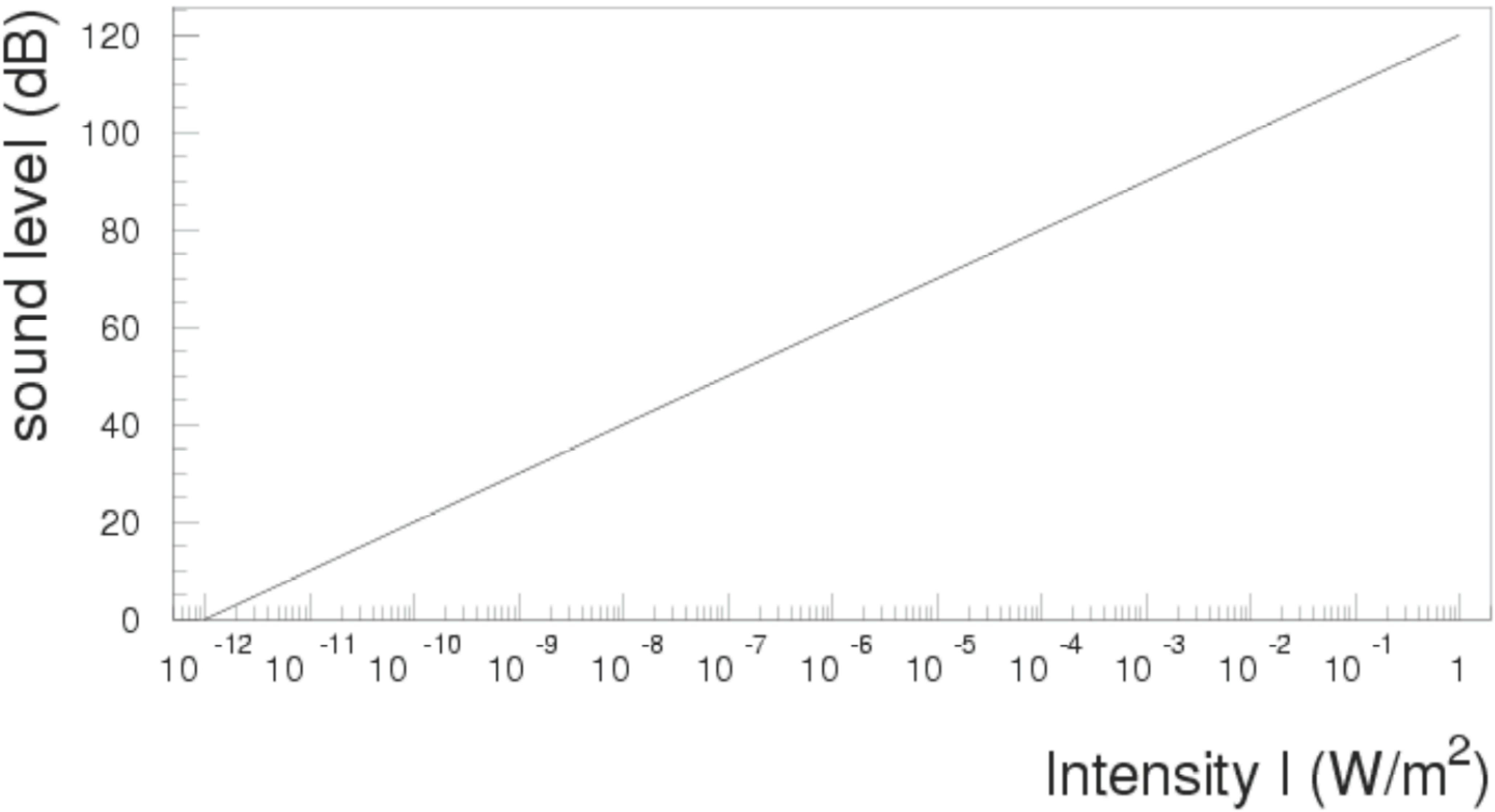
"The power to which the base 10 must be raised to give 100 is 2"

"The logarithm to the base 10 of 100 is 2"

$$\text{Log}_{10}100 = 2$$

Decibel level β

$$\beta = 10 \log(I/I_0) \qquad I_0 = 10^{-12}\ W/m^2$$



decibels

$$\beta = 10 \log(I/I_0) \quad I_0 = 10^{-12}\ W/m^2$$

Source of Sound	β (dB)
Nearby jet airplane	150
Jackhammer, machine gun	130
Siren, rock concert	120
Subway, power mower	100
Busy traffic	80
Vacuum cleaner	70
Normal conversation	50
Mosquito buzzing	40
Whisper	30
Rustling leaves	10
Threshold of hearing	0

An increase of 10 dB: intensity of the sound is multiplied by a factor of 10.

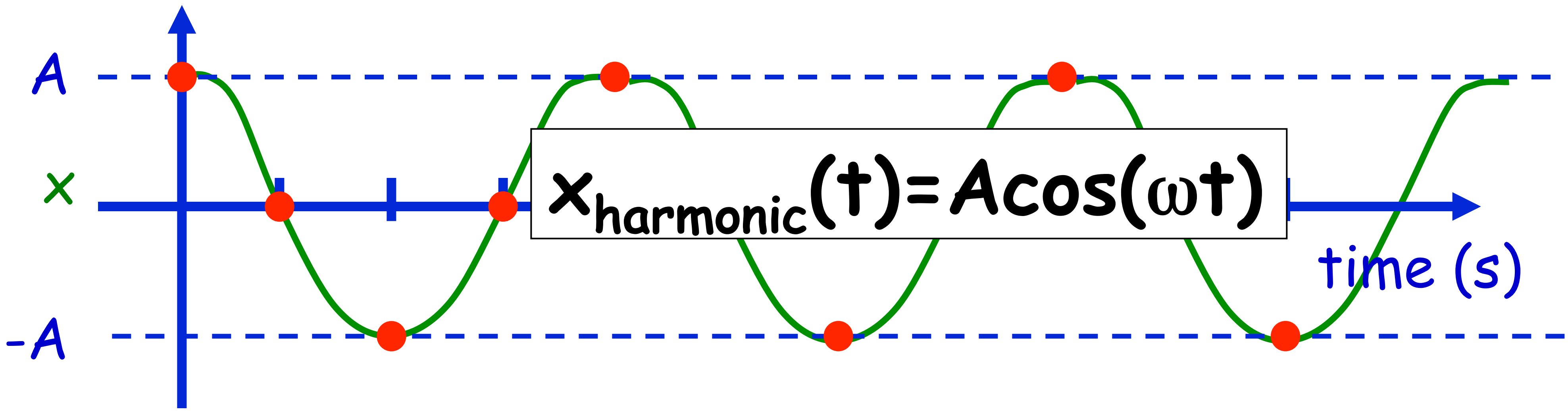
Example

A machine produces sound with a level of 80dB. How many machines can you add before exceeding 100dB?

Each time sound increases by 10dB, intensity is multiplied by 10 → from 80dB to 100dB intensity is multiplied by 10 x 10 = 100.

Thus one needs 99 more machines (99 + 1 = 100) to increase sound from 80dB to 100dB.

Relation between amplitude and intensity

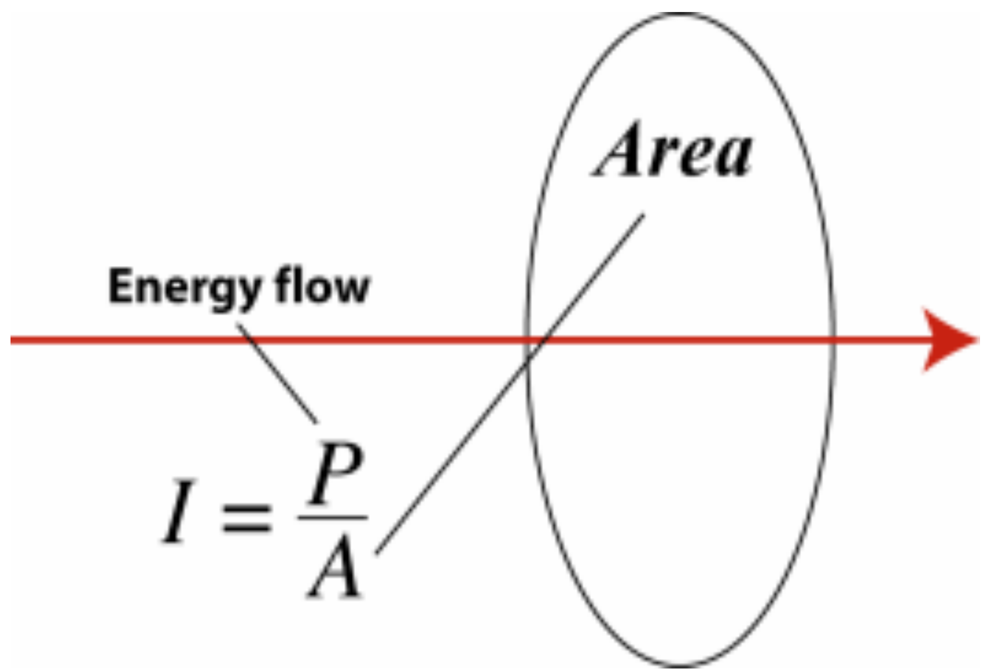


For sound, the intensity I goes linear with the amplitude of the longitudinal wave squared

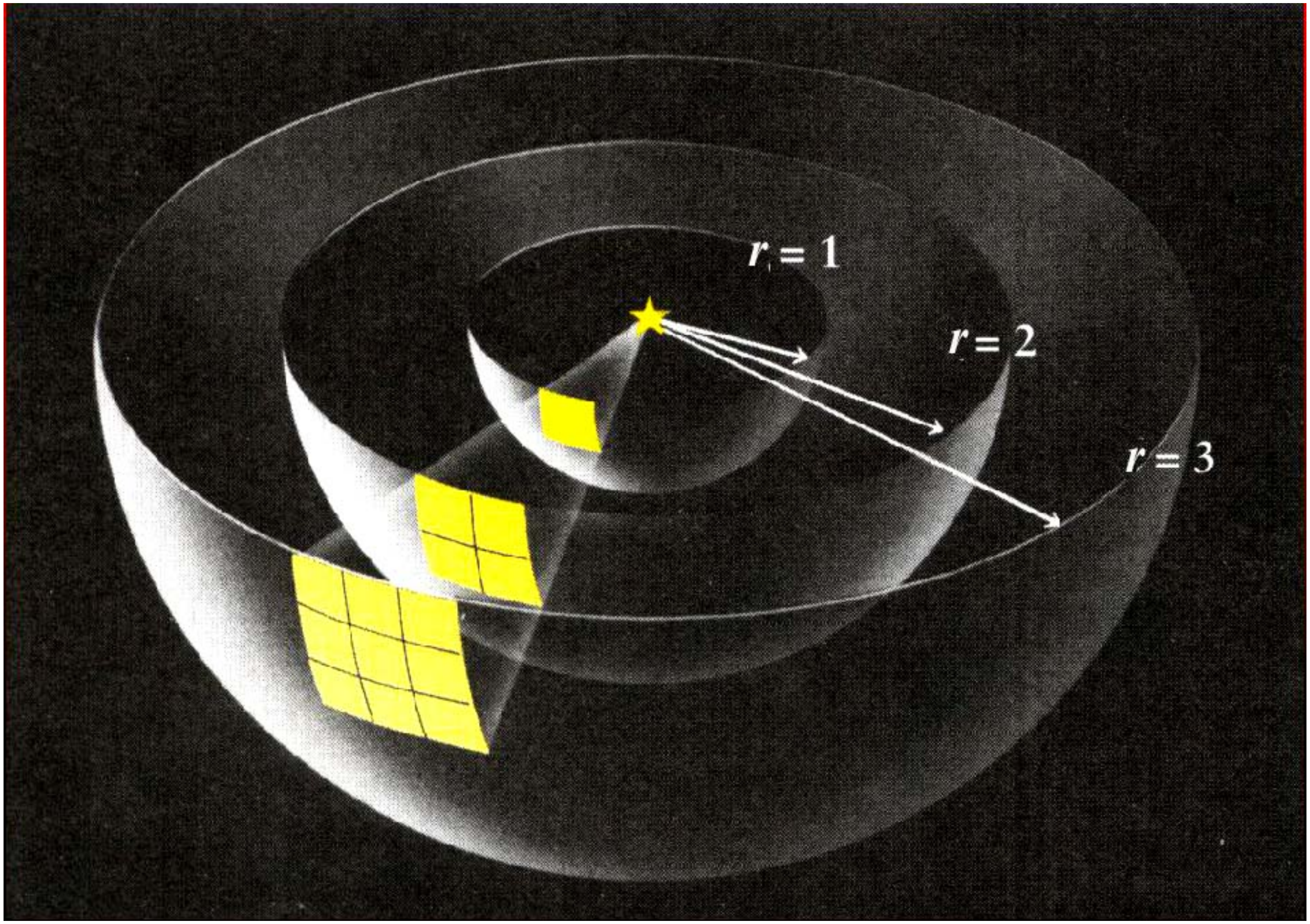
$$I \sim A^2$$

Energy and Intensity

- Intensity
  - Energy flowing (power) through a given area
  - Proportional to amplitude of sound wave, squared
  - Units = W/m^2



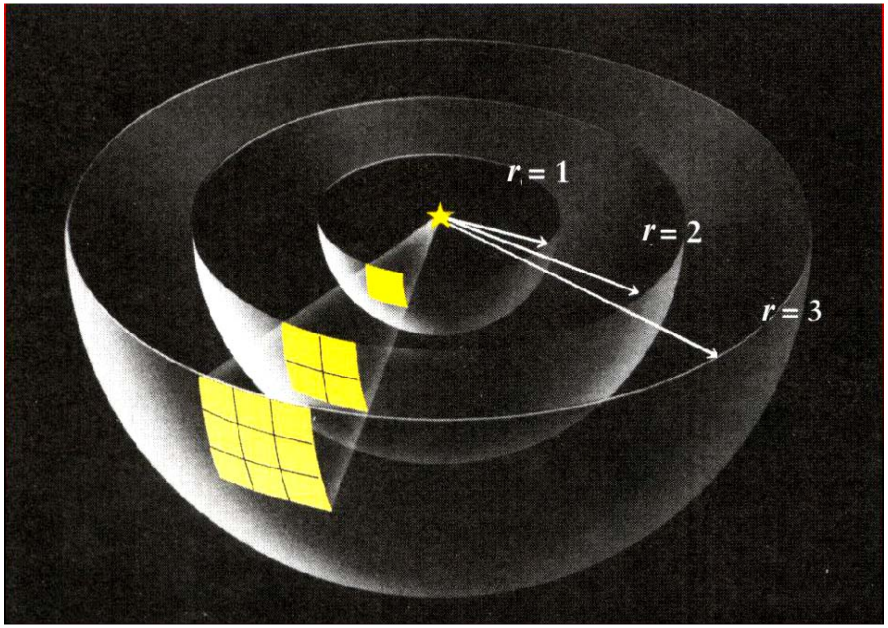
Intensity and distance from the source



Sound from a point source produces a spherical wave.

Why does the sound get fainter further away from the source?

Intensity and distance



The amount of energy passing through a spherical surface at distance r from the source is constant, but the surface becomes larger.

$I = Power/Surface = P/A = P/(4\pi r^2)$

r=1 $I=P/(4\pi r^2)=P/(4\pi)$
1

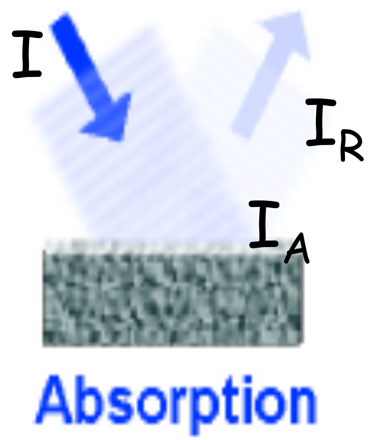
r=2 $I=P/(4\pi r^2)=P/(16\pi)$
4

r=3 $I=P/(4\pi r^2)=P/(36\pi)$
9

Sound absorption

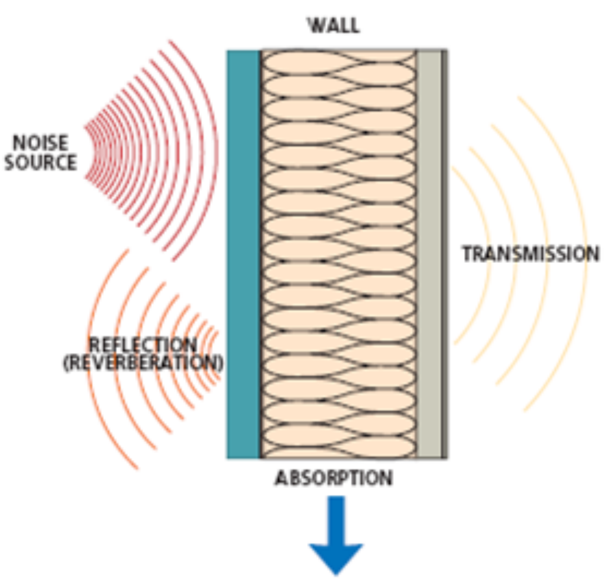
When sound reflects, part of its initial intensity I is absorbed:

$I_R = I - I_A$



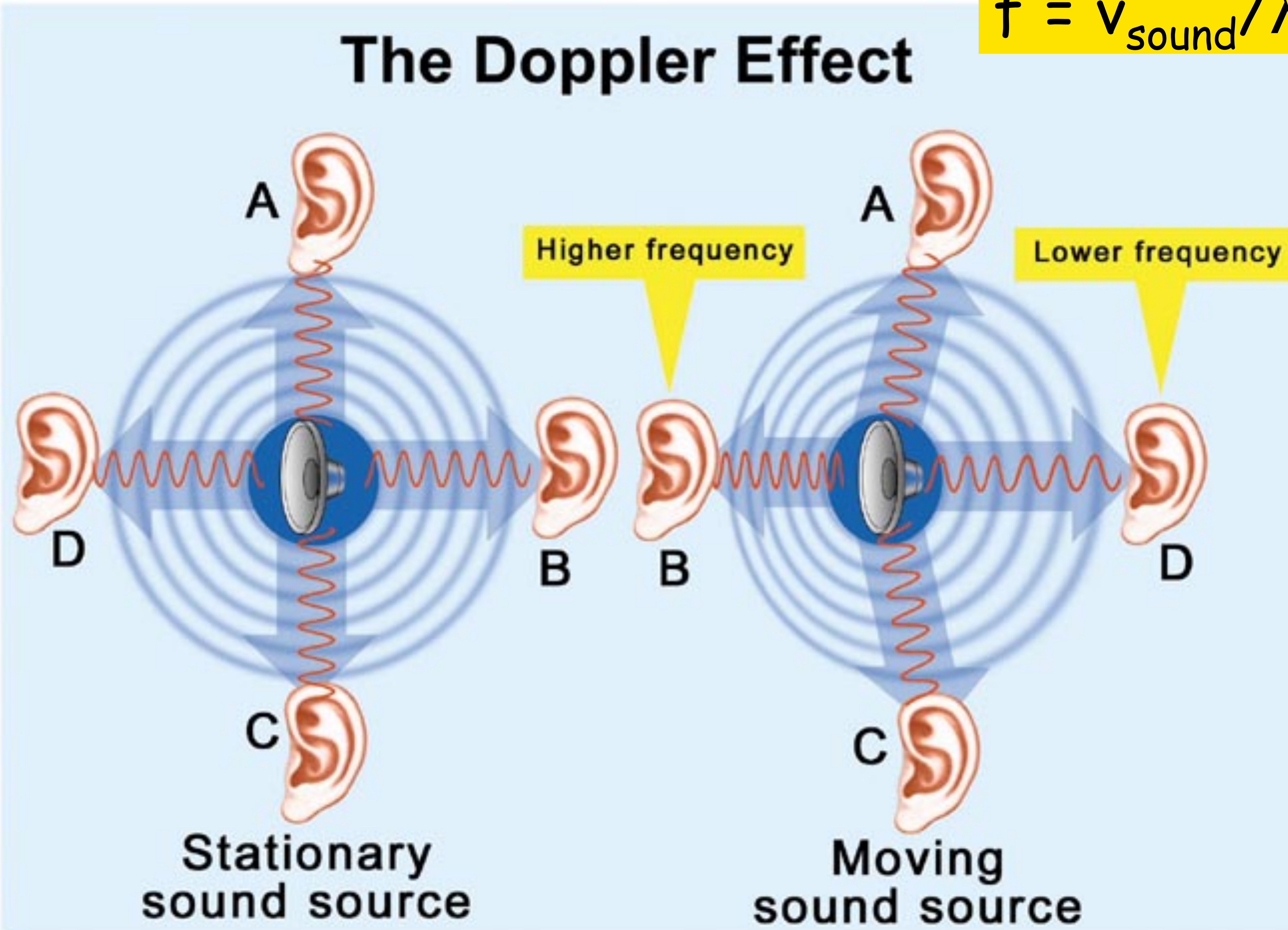
Absorption coefficient $a = I_A/I$

a = 0 (total reflection)
(generally lower frequencies)

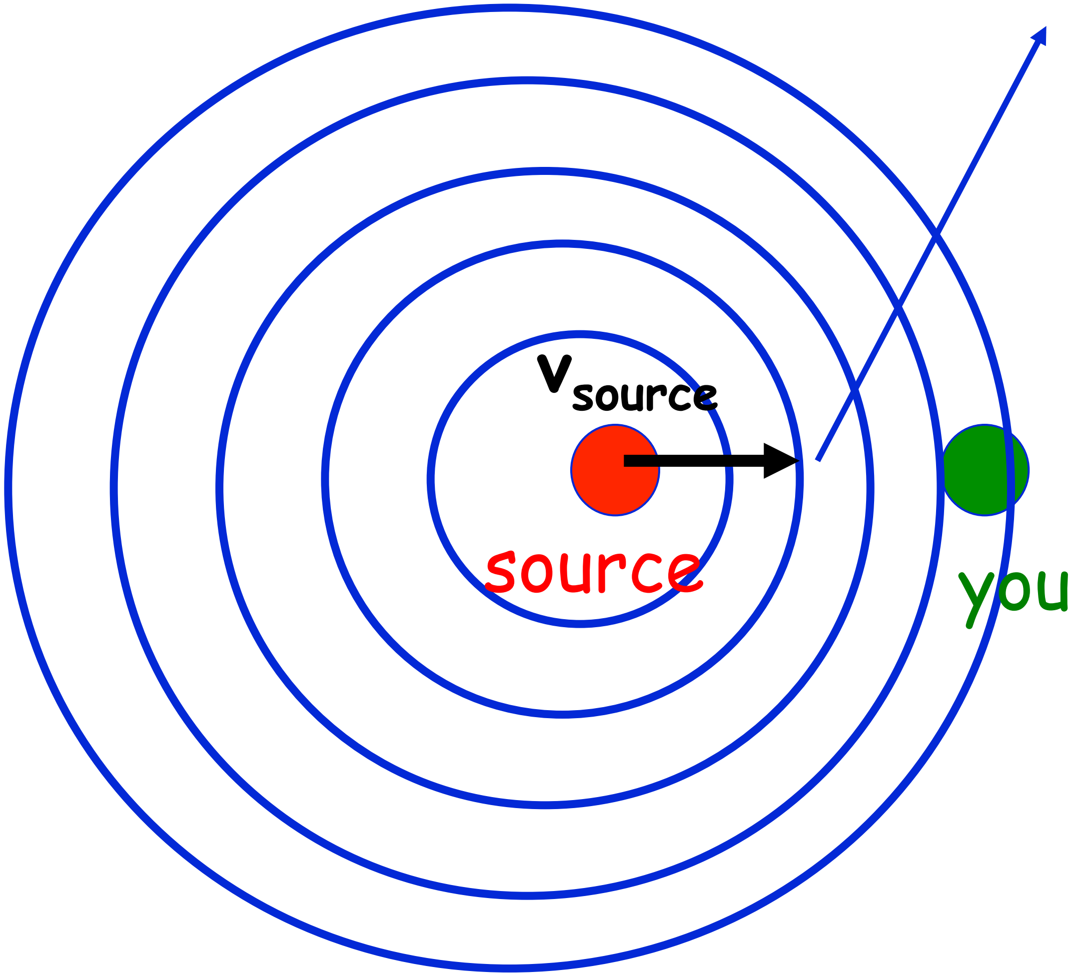


a = 1 (total absorption)
(generally higher frequencies)

$f = v_{sound}/\lambda$



Doppler effect: a <u>source moving towards</u> you

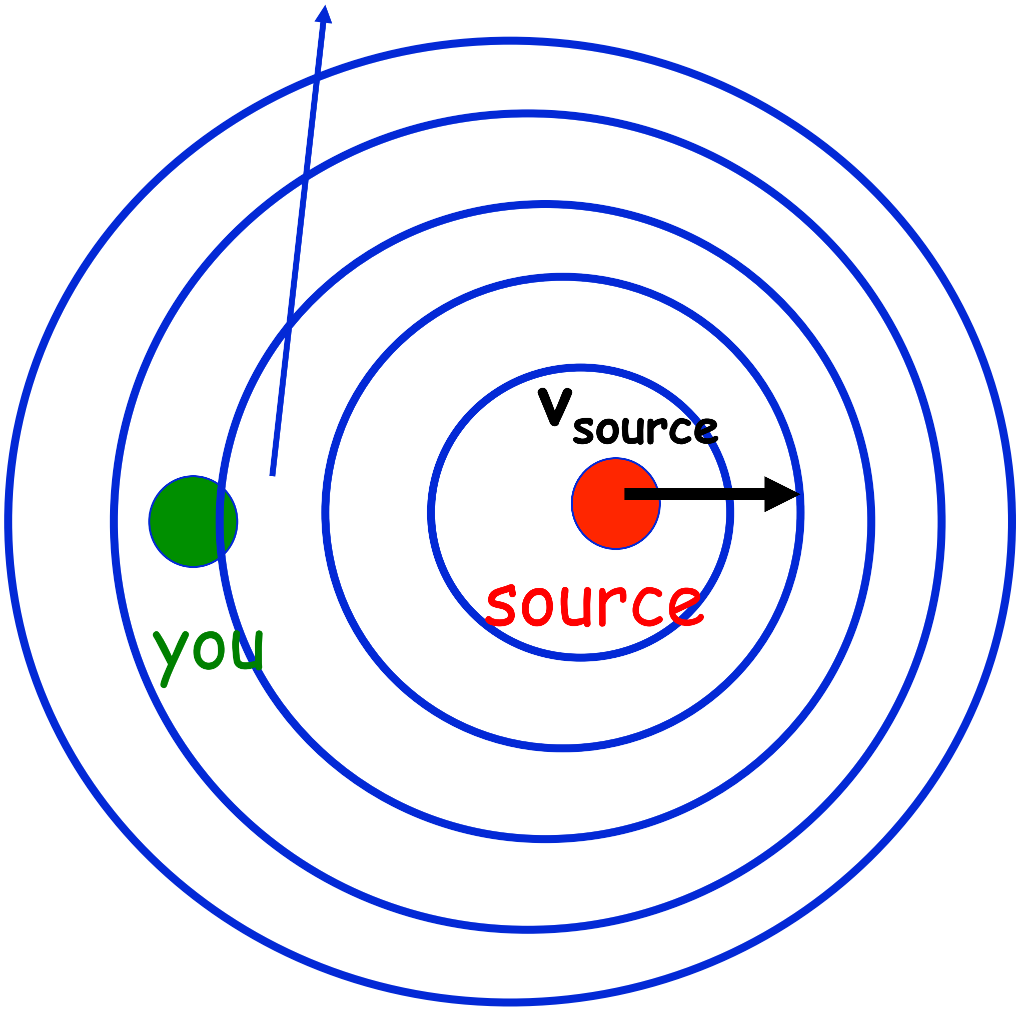


the distance between the wave front is shortened

The frequency becomes larger: higher tone

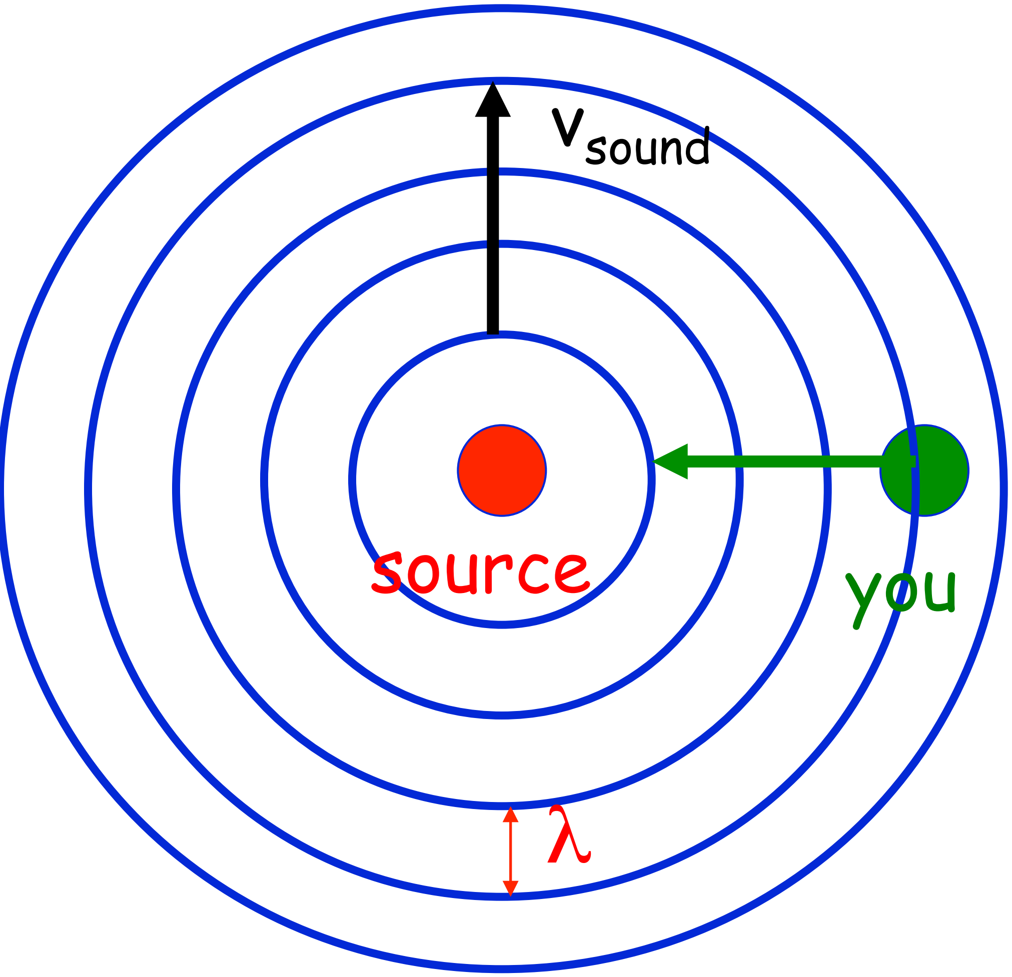
Doppler effect: a source moving away from you

the distance between
the wave front becomes longer



The frequency becomes lower: lower tone

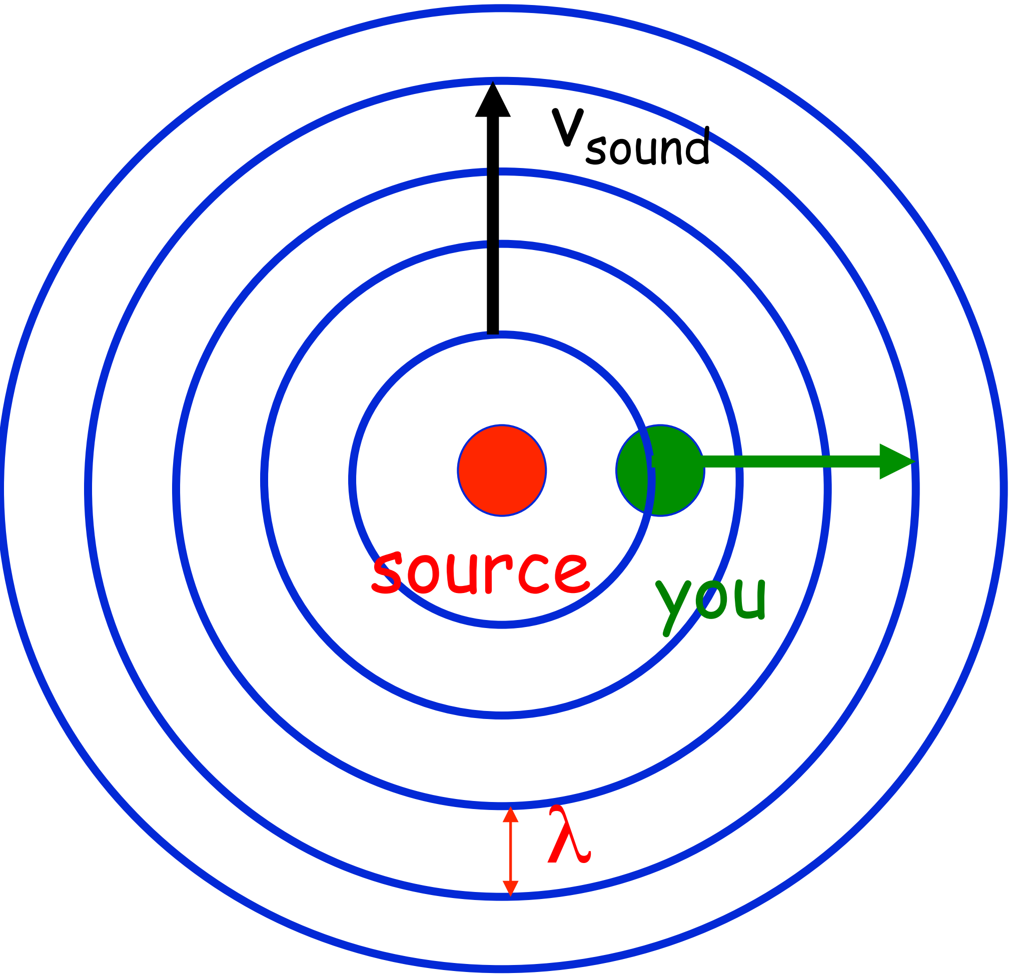
Doppler effect: you moving towards the source



additional wavefronts detected per second:

The frequency becomes larger: higher tone

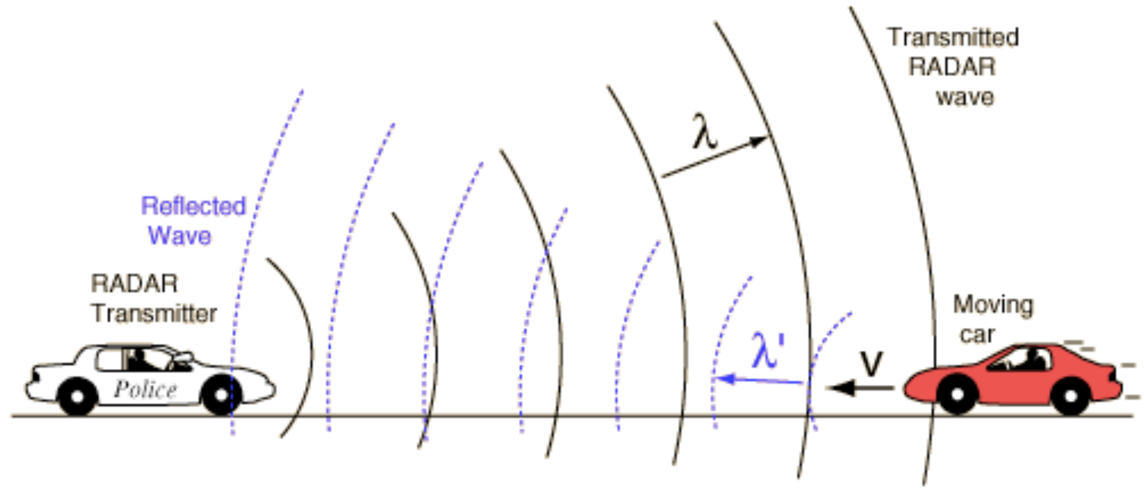
Doppler effect: <u>you moving away</u> from the source



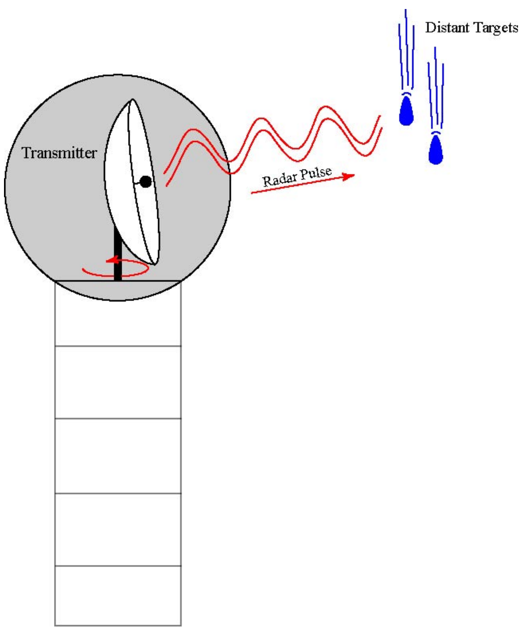
less wavefronts detected per second:

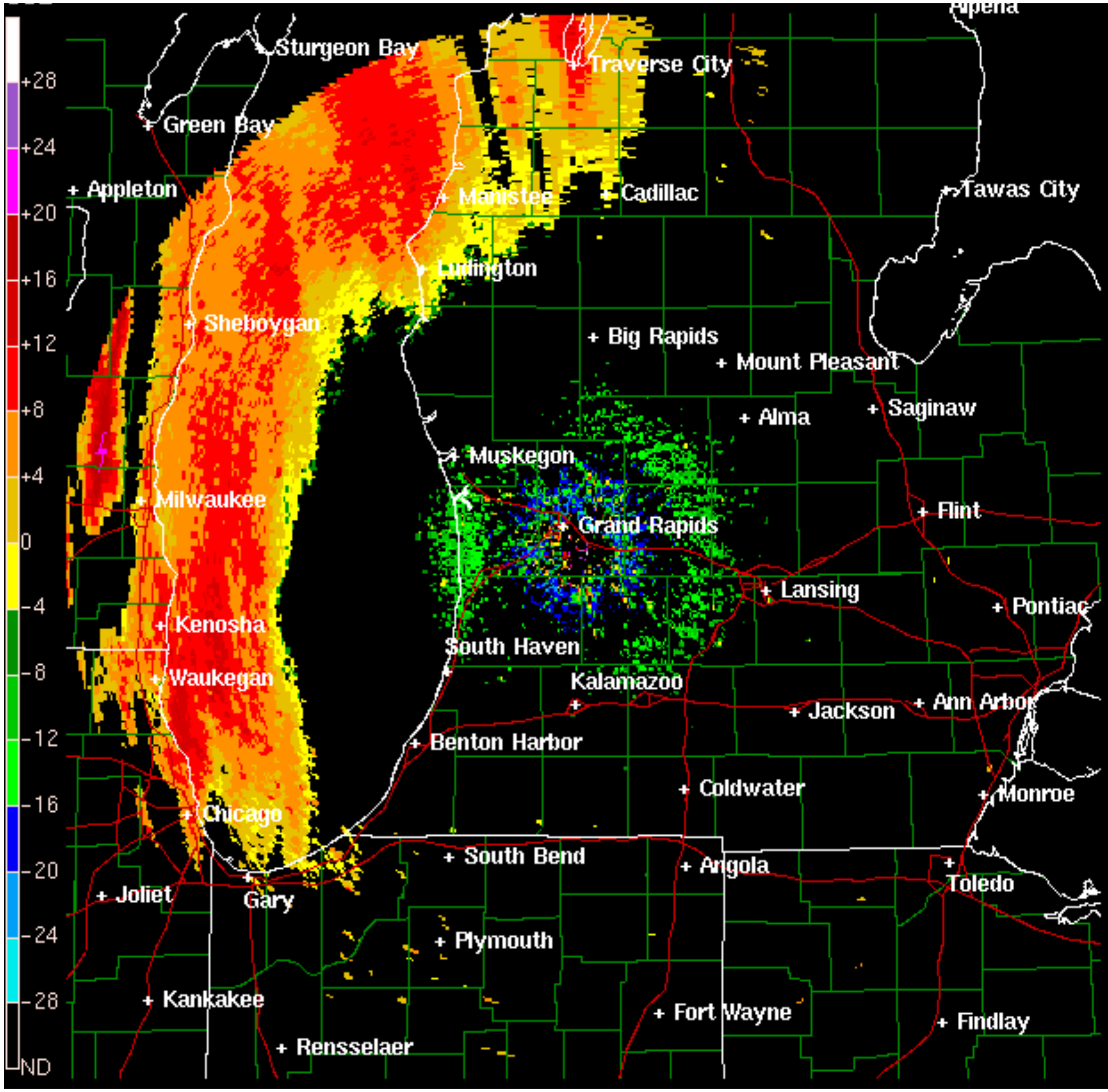
The frequency becomes lower: lower tone

Applications of the doppler effect: speed radar



Applications of doppler effect: weather radar

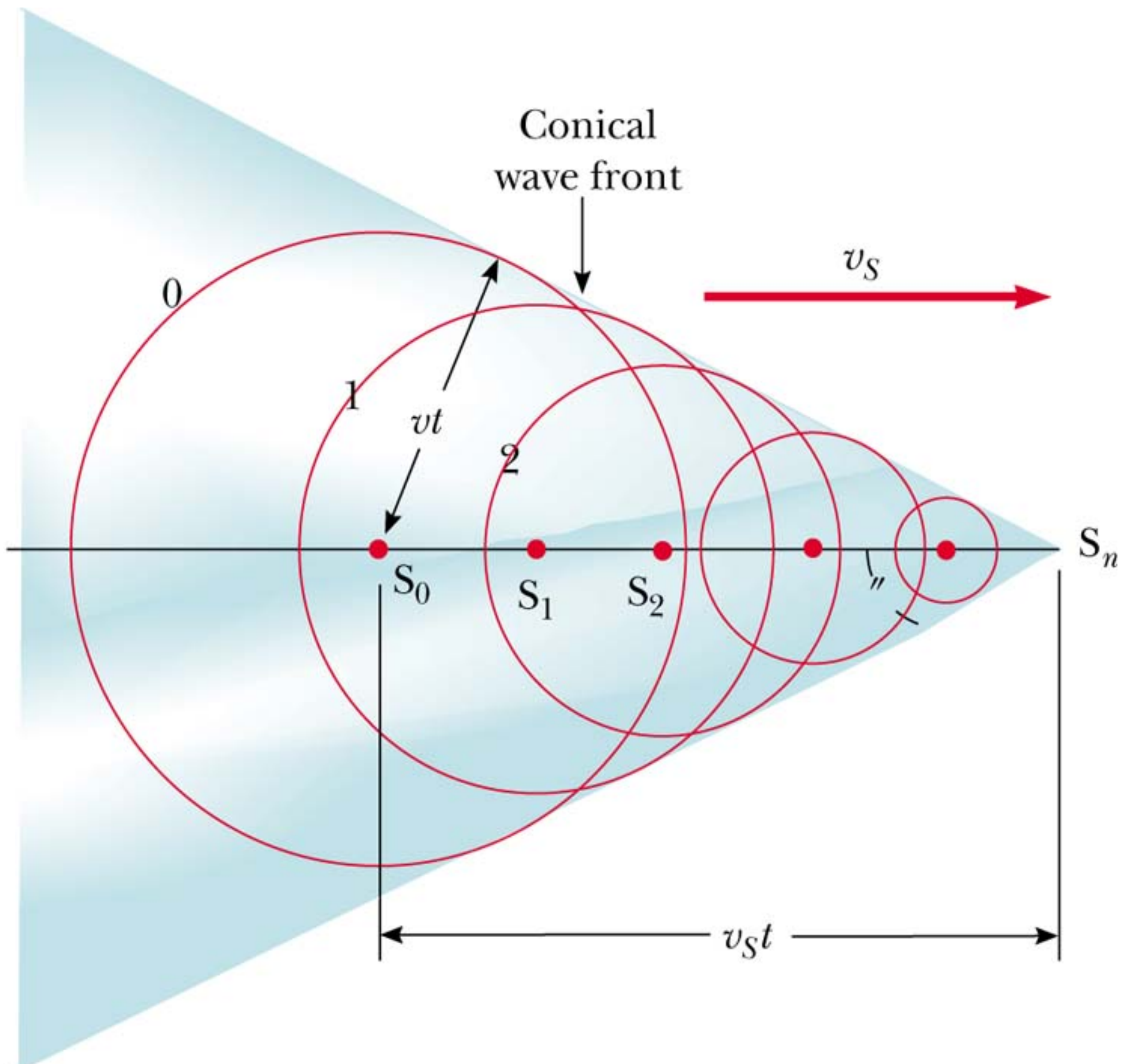




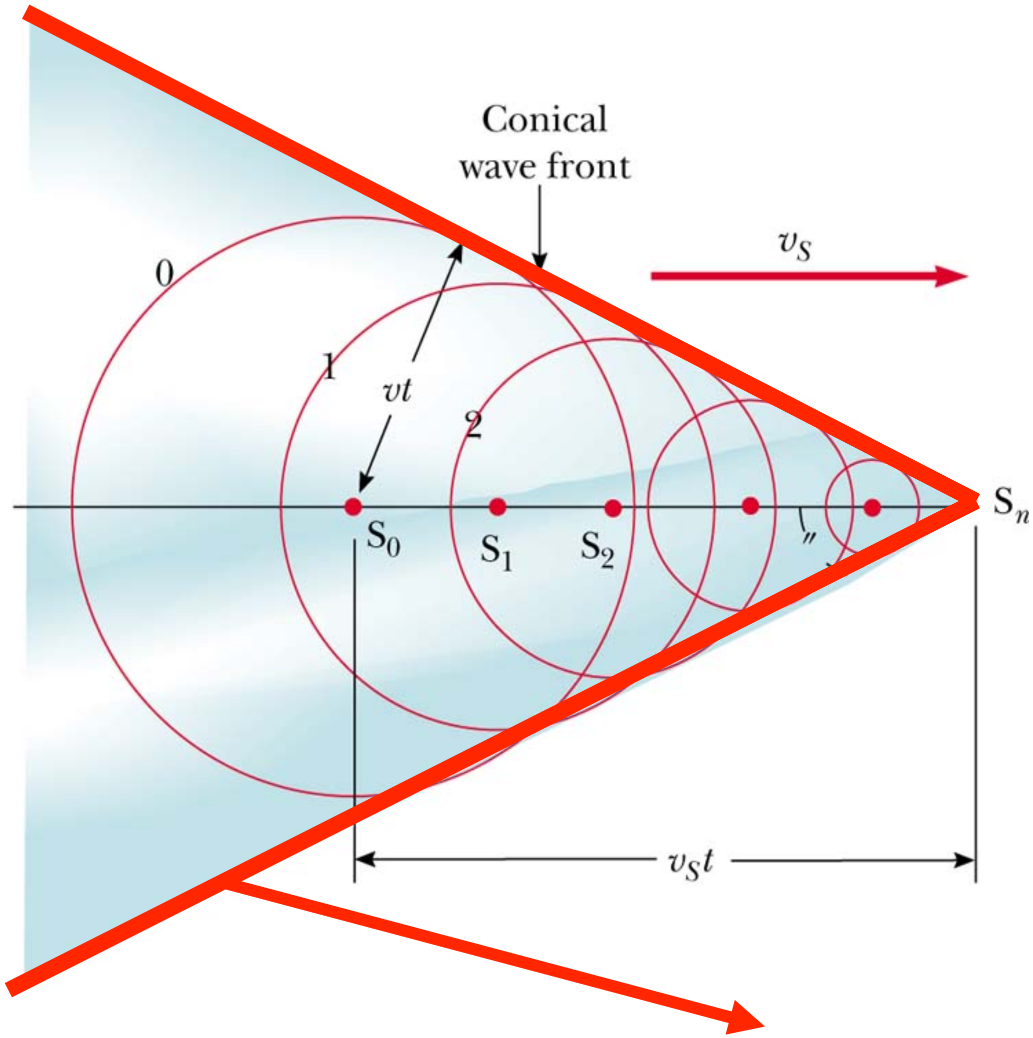
Both humidity (reflected intensity) and speed of clouds (doppler effect) are measured.

Shock waves

what happens if $v_{source} \geq v_{sound}$?



Shock waves



$\sin\theta = v_{sound}/v_{source}$

v_{source}/v_{sound} = **Mach**

Mach 1: speed of sound.

Mach 2: 2 times speed of sound, etc

high-pressure wave
a lot of energy is stored in the wave
(loud bang, vibrations, broken windows)