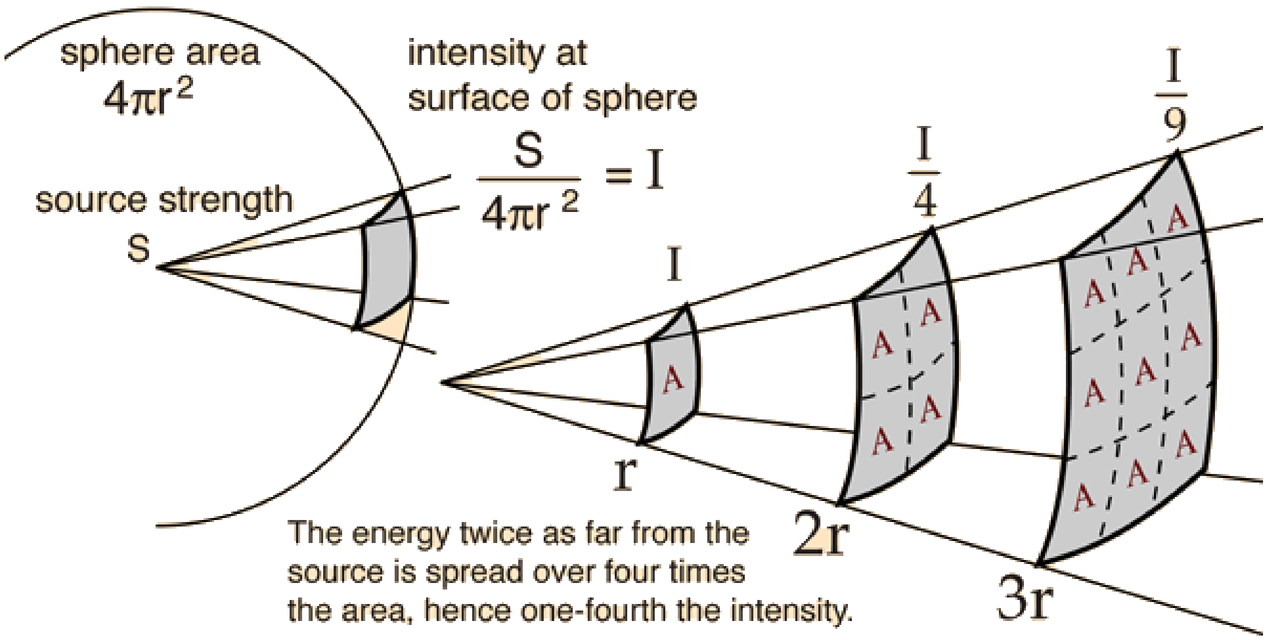
Inverse-square law

The inverse-square law, in physics, is any physical law stating that a specified physical quantity or intensity is inversely proportional to the square of the distance from the source of that physical quantity.

While the wave propagates in a spherical form from the source, the sound intensity decreases according to the inverse square law. The intensity is distributed over the entire surface of the sphere as the sound moves away from the source. Since the surface of the sphere is given by $4\pi r^2$, the intensity decreases with the square of the distance from the source.

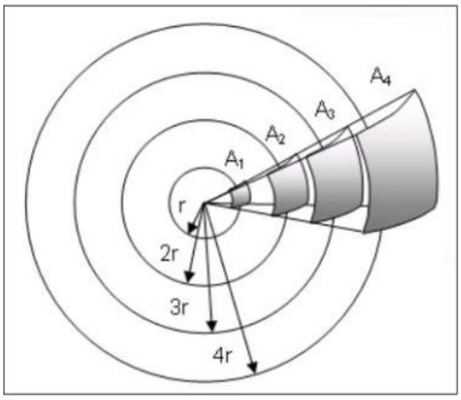


The sound power per unit area (sound intensity) decreases proportionally to the square of the radius (distance).

In the free air the sound propagates uniformly in all directions, and its intensity decreases with increasing distance from the source. The same sound power passes through each area, but the areas increase proportionally to the square of the radius.

Example

The same sound power passes through A1, A2, A3 and A4, but the areas increase proportionally to the square of the radius.



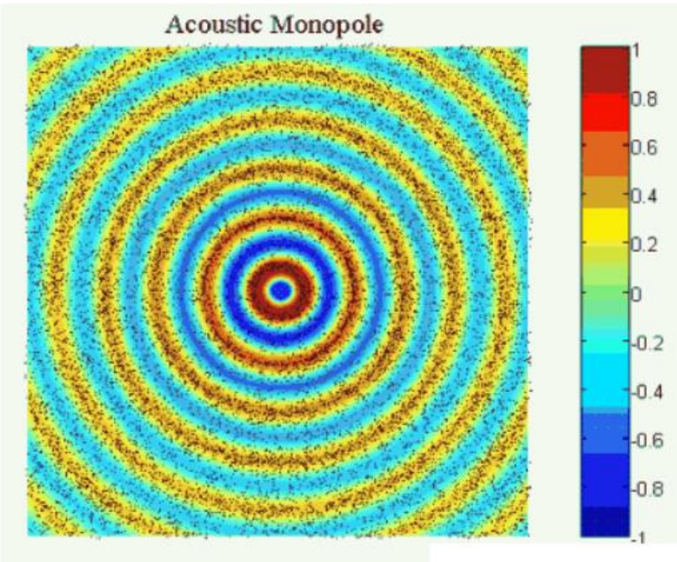
This means that the power of the sound per unit area (sound intensity) decreases proportionally to the proportional square of the ray.

The intensity of sound in free field is inversely proportional to the square of the distance from the source.

Distance: 2 x r → Intensity: 1/4 x $Intensity_o$
Distance: 3 x r → Intensity: 1/9 x $Intensity_o$
Distance: 4 x r → Intensity: 1/16 x $Intensity_o$

Acoustic Monopole (damped harmonic oscillator)

The case of the acoustic monopole summarizes the law of the inverse of the square.



Amplitude

The monopole considered as a **point source** (it is defined as a point source when the latter has dimensions much smaller than the wavelength in play) emits spherical waves in the surrounding environment in the absence of obstacles. The sound that will be radiated will be uniform in all directions and the sound intensity will decrease more and more as the distance increases.

The law of the inverse of the square establishes that the intensity of the sound in free field is inversely proportional to the square of the distance from the source. If the distance doubles, the intensity is reduced to 1/4; if it triples, the intensity is reduced to 1/9; if it quadruples, the intensity is reduced to 1/16.

Example

A sound is heard with intensity 90 W/m² at a distance of five meters. What will the perceptual intensity be 15 meters away?

$r_o = 5$, $r_1 = 15$

$r_1/r_o = 15/5 = 3r_o$

$3^2 = 9$

$90/9 = \underline{10 W/m^2}$

Speed of sound

The speed of sound is the speed with which a sound propagates in a certain environment.

- The speed of sound varies depending on the medium (for example, the sound propagates faster in the water than in the air)
- varies with the properties of the medium, especially with its temperature.

In the air, the speed of sound at 0 ° C is 331 m / s (equal to 1,191.60 km / h).

Approximating we can derive a linear law V (T) = (331.45 + (0.62 * T)) m / s with T the temperature measured in ° C).

$$v_{m,T} = v_{m,0} + \alpha_m(T)$$

$$v_{air,\,0} = 331{,}45\ \frac{m}{s}$$
$$\alpha_{air}(T) = 0{,}62\ T$$

Example

▫ $T_1 = 0°C$	speed = <u>331,45 m/s</u>
▫ $T_2 = 20°C$	V (T) = (331.45 + (0.62 * 20)) m / s → speed = <u>343,85 m/s</u>
▫ $T_3 = -20°C$	V (T) = (331.45 + (0.62 * -20)) m / s → speed = <u>319,05 m/s</u>
▫ $T_4 = 35°C$	V (T) = (331.45 + (0.62 * 35)) m / s → speed = <u>353,15 m/s</u>

The minimum speed limit for a sound that travels in the air is 162 m / s.

We cannot get a temperature below absolute zero: -273.15 ° C

Therefore:

331.45 - (0.62 * 273.15) = 331.45 - 169.353 = <u>162.097 m/s</u>

The speed of sound propagation is greater in solids than in fluids.

Medium	Speed ($m\ s^{-1}$)
Gases	
Air (0 °C)	331
Air (20 °C)	343
Helium	965
Hydrogen	1284
Liquids	
Water (0 °C)	1402
Water (20 °C)	1482
Seawater	1522
Solids	
Aluminium	6420
Copper	3560
Steel	5941
Granite	6000
Vulcanised Rubber	54

Compressibility is the deciding factor for the transmission speed.

The transmission speed depends on the speed with which each layer is compressed and expanded again. The less the layer is compressible, the sooner the energy is released to the next one.

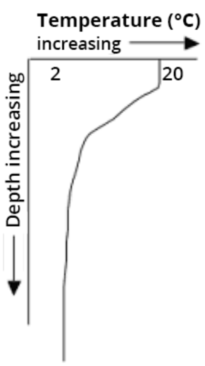
Example

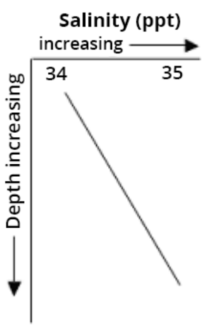
Speed of sound in sea water

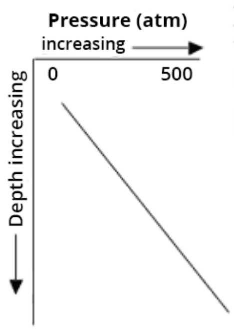
- varies between 1460 and 1560 m / s
- At the sea surface (depth 0 meters), at 21 ° C, with a normal salinity of 32 parts (out of 1000), the speed of sound is 1505 m / s

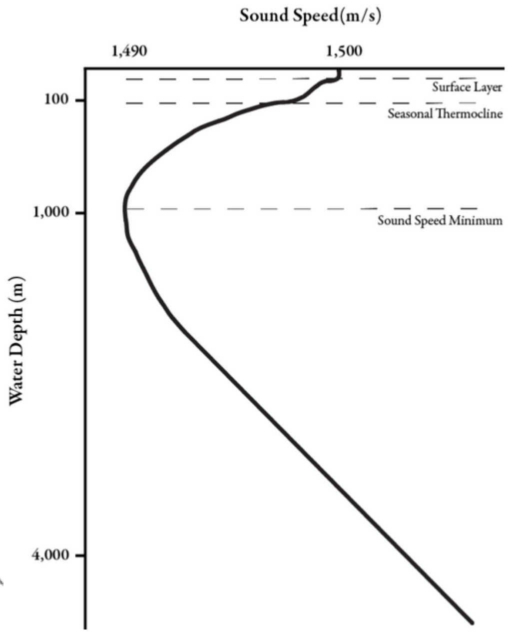
$$V = 1450 + 4.61 \cdot T - 0.045 \cdot T^2 + 0.0182 \cdot h + 1.3 \cdot (S - 34)$$

T	h	S
Temperature	Depth	Salinity









The sound speed at the surface is fast because the temperature is high from the sun warming the upper layers of the ocean. As the depth increases, the temperature gets colder and colder until it reaches a nearly constant value. Since the temperature is now constant, the pressure of the water has the largest effect on sound speed. Because pressure increases with depth, sound speed increases with depth. Salinity has a much smaller effect on sound speed than temperature or pressure at most locations in the ocean. This is because the effect of salinity on sound speed is small and salinity changes in the open ocean are small. Near shore and in estuaries, where the salinity varies greatly, salinity can have a more important effect on the speed of sound in water.

Question:

Can we hear sound on Titan?

Yes! Because any kind of matter can transmit sound waves, we can hear sound in any place with atmosphere.

Since the planetary atmospheres are made of different materials and are exposed to different conditions - for example, the Titan's atmosphere is mainly nitrogen, like ours, but about four times as dense as the air at sea level - the sounds probably sound rather strange.

We could hear or record these with microphones.

Wavelength

Once the sound speed has been set and the frequency has been set, the wavelength can be calculated. We remember:

$$\lambda = \frac{v}{f}$$

$$\frac{343{,}85\frac{m}{s}}{20Hz} = 17{,}19m$$

$$\frac{343{,}85\frac{m}{s}}{20000Hz} = 17{,}19 \cdot 10^{-3}m = 17{,}19mm$$

Audible wavelengths of humans: The audible frequency range is between 20 Hz and 20 kHz, from which we can derive the wavelengths for the frequency extremes. In 20 ° C air, the range of audible wavelengths ranges from **17m** to **17mm**.