# Sound Reflection（声反射）

The process of wave reflection may be defined as the return of all or part of a sound beam when it encounters the boundary between two media. The most important rule of reflection is that the angle of incidence is equal to the angle of reflection. Where both these angles are measured relative to an imaginary line which is normal to the boundary. Reflection is often quantified in term of the reflection coefficient '*R*'. *R* is defined simply as the ratio of the reflected and incident wave amplitudes.

$$R = a_r / a_i$$

Where '$a_i$' and '$a_r$' are the incident and reflected wave amplitudes respectively. The value of the reflection coefficient relates to the magnitude of reflection from the interface between two media with different physical properties.

In underwater acoustics the acoustic impedance (z) of the two media involved dictates the magnitude of reflection from a boundary. The acoustic impedance is simply the product of the density (r) and the sound speed (c) of the fluid.

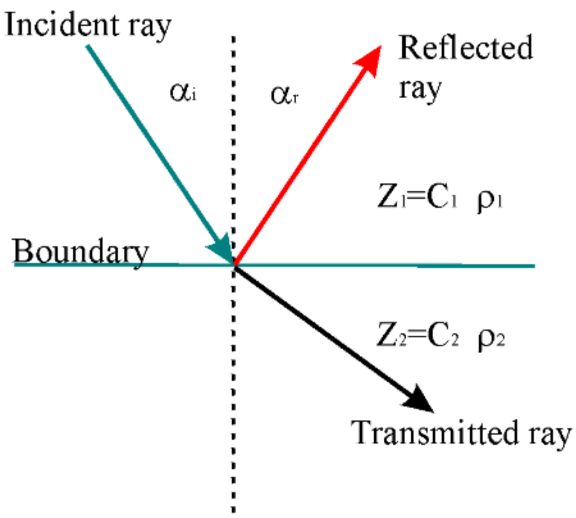
$$z = c\ r$$

Acoustic impedance is measured in **Rayles** (1 Rayle = 1 m/s.kg/m$^3$ = 1 kg/m$^2$/s).

The full expression for sound reflection coefficient is:

$$R = \frac{(z_2/z_1) - \sqrt{1-[n-1]\tan^2\alpha_i}}{(z_2/z_1) + \sqrt{1-[n-1]\tan^2\alpha_i}}$$

Here $n = (c_2 / c_1)^2$ and $a_i$ is the angle of incidence of the wave ray. A definition sketch is given below to help you:



Notice that since energy is always conserved the remaining energy that is not absorbed must be either dissipated (e.g. in the form of heat) or transmitted into the second medium whereby it will undergo refraction if the velocities in the two layers differ. If dissipation is negligible (a loss-less medium) the amplitude of the transmitted wave will be (1-*R*).

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If the waves are normally incident to the boundary the reflection equation can be simplified to:

$$R = \frac{(z_2 - z_1)}{(z_2 + z_1)} \qquad \text{for } \alpha_i = 0$$

Thus, acoustic reflection is a simple function of the impedance of the two media. If the two media have the same impedance there will be no reflection. Since the impedance is the product of velocity and density it is possible for example to have two media with different densities or sound speed but the same acoustic impedance.

Acoustic reflection coefficients have values that range between -1 and +1. From this range we can identify 4 different types of reflection:

1) $z_2 >> z_1$, $R => 1$ (Rigid boundary), i.e. most of the acoustic energy will be reflected without a change in phase.

2) $z_2 << z_1$, $R => -1$ (Soft or pressure release boundary), i.e. most of the acoustic energy is reflected with a 180 degree phase change.

3) $z_1 = z_2$, $R = 0$, (No Reflection)

4) Similar acoustic impedance, $-1 << R << 1$, some phase change.

Probably the most important thing to remember is that acoustic reflection will be strong anywhere there are strong spatial gradients in acoustic impedance. Some typical examples of impedance for different materials and their reflection coefficient in salt water are given below:

| **Material** | **Impedance, z (Rayles)** | **R** |
|---|---|---|
| Air: | 415 | -1 |
| Fresh water: | 1 480 000 | 0.04 |
| Salt water: | 1 540 000 | 0 |
| Wet fish flesh: | 1 600 000 | 0.02 |
| Wet fish bone: | 2 500 000 | 0.24 |
| Rubber: | 1 810 000 | 0.08 |

| | | |
|---|---|---|
| Granite: | 16 000 000 | 0.82 |
| Quartz: | 15 300 000 | 0.81 |
| Clay: | 7 700 000 | 0.67 |
| Sandstone: | 7 700 000 | 0.66 |
| Concrete: | 8 000 000 | 0.68 |
| Steel: | 47 000 000 | 0.94 |
| Brass: | 40 000 000 | 0.92 |
| Aluminium: | 17 000 000 | 0.83 |

Try and classify the above into rigid soft and weakly reflective boundaries.

An examination of the figures above you should tell you why military submarines often have rubber coatings in order to minimise reflection and avoid detection (compare the reflection coefficients of steel and rubber).

Bearing in mind that fish flesh and bone have relatively low reflection coefficients why is do you think that we are able to detect fish so effectively with fish finding echo sounders? (Hint consider how fish control their buoyancy)

We will see later in our discussion of the sonar equations that the reflectivity of different surfaces has implications to the target strength of different objects that we might wish to detect acoustically. The target strength is a measure of the ratio of the reflected to incident intensities at set distance away from the target and is therefore by definition related to the reflection coefficient.

The fact that different materials have different acoustic impedance and reflection coefficients allows us to acoustically distinguish between different targets. Side-scan sonar for example uses this characteristic to distinguish between sand (predominantly quartz), mud and rock. This is done by examining the difference in intensity of the acoustic returns, often in conjunction with some sort of textural analysis.

**Exercise**

Compute the magnitude of the reflection and transmission coefficients at the boundary between a fresh upper layer and a saline lower layer of water in a salt wedge estuary. Assume that the angle of incidence of the acoustic ray is 5 degrees. The characteristics of the fresh and saline water are as follows:

Fresh water: c=1426m/s, density = 1000kg/m$^3$
Saline water: c=1519m/s, density = 1025kg/m$^3$