THE NATURE OF SOUND WAVES

MU610A: ACOUSTICS & PSYCHOACOUSTICS

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FUNDAMENTAL ITEMS

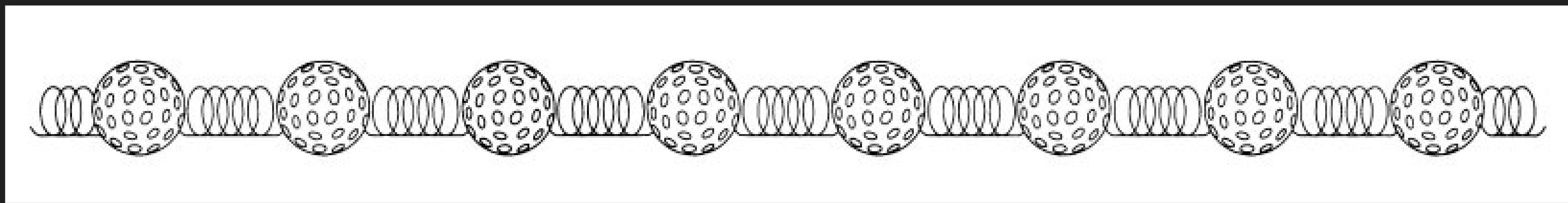
- What is sound?
- Compression and Rarefaction
- Velocity
- Golf Ball & Spring Model
- Propagation
- Longitudinal and Transverse waves
- Attenuation

SOUND WAVES

- Sound is a result of vibrations within a medium. It travels through the medium in waves. We say 'waves' because sound propagates in a medium through waves of pressure.
- If the molecules in the medium are disturbed, a wave will travel through the medium.

SOUND WAVES

- The 'golf ball and spring' model from Howard and Angus shows this:



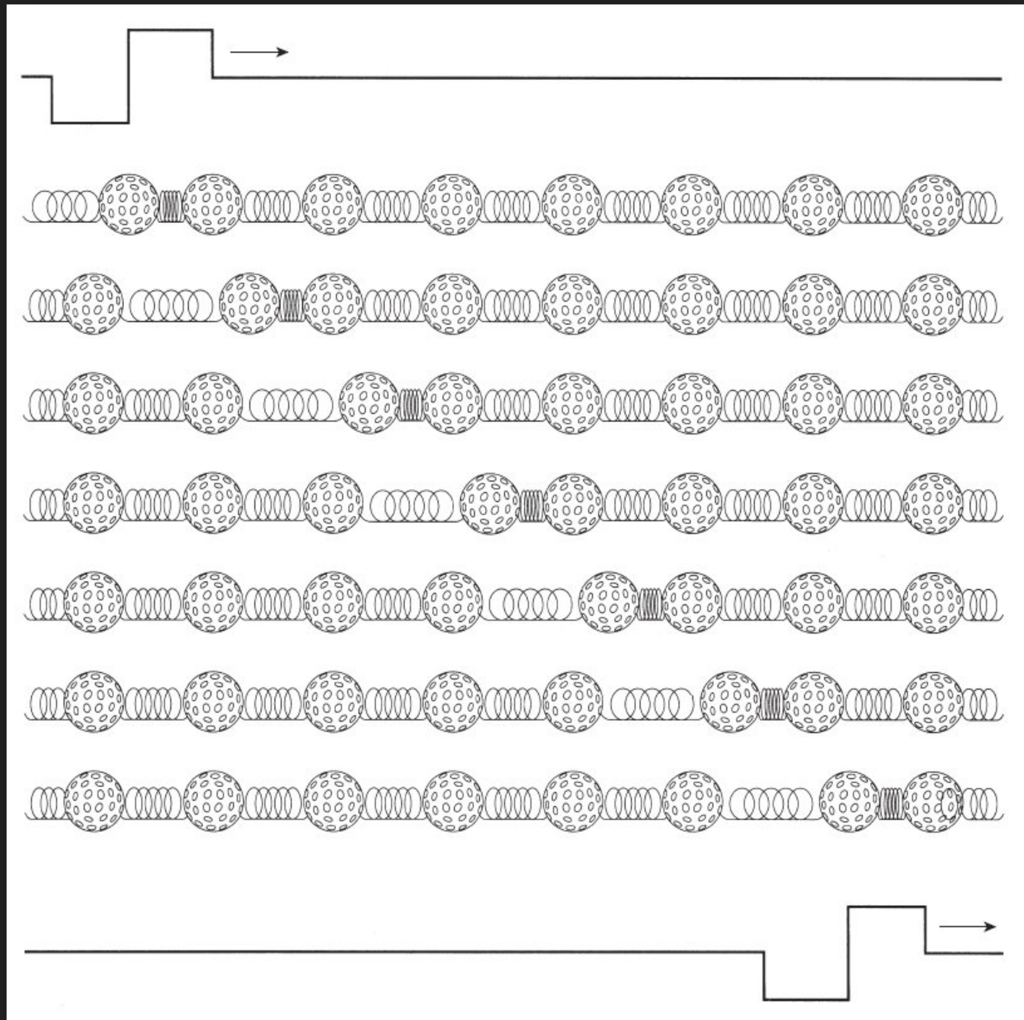
SOUND WAVES

- This model is used to show how sound travels through a physical medium, such as air. It shows a series of golf balls, which could be any objects, connected with springs.
- In a real material, molecules will be connected by intermolecular forces. Thus golf balls represent molecules/masses and the springs represent the forces between these molecules.

SOUND WAVES

- By pushing the golf ball on the extreme left towards the right, the spring in between the first and second ball will be compressed. This compression will act on the seconds ball, which will then compress the next spring, etc.

SOUND WAVES



SOUND WAVES

- The creation of a sound "wave":
  - When particles are pushed together, they compress causing a 'crest'
  - When particles are pulled apart, there is a moment of rarefaction causing a 'trough'

SOUND WAVES

- If the 1st golf ball is moved back to the original position, the golf balls will be pulled rather than pushed together, starting the process again.
- Note that the disturbance caused by moving the 1st golf ball will take some time to the other end. This is why sound is not instantaneous. It has a speed.

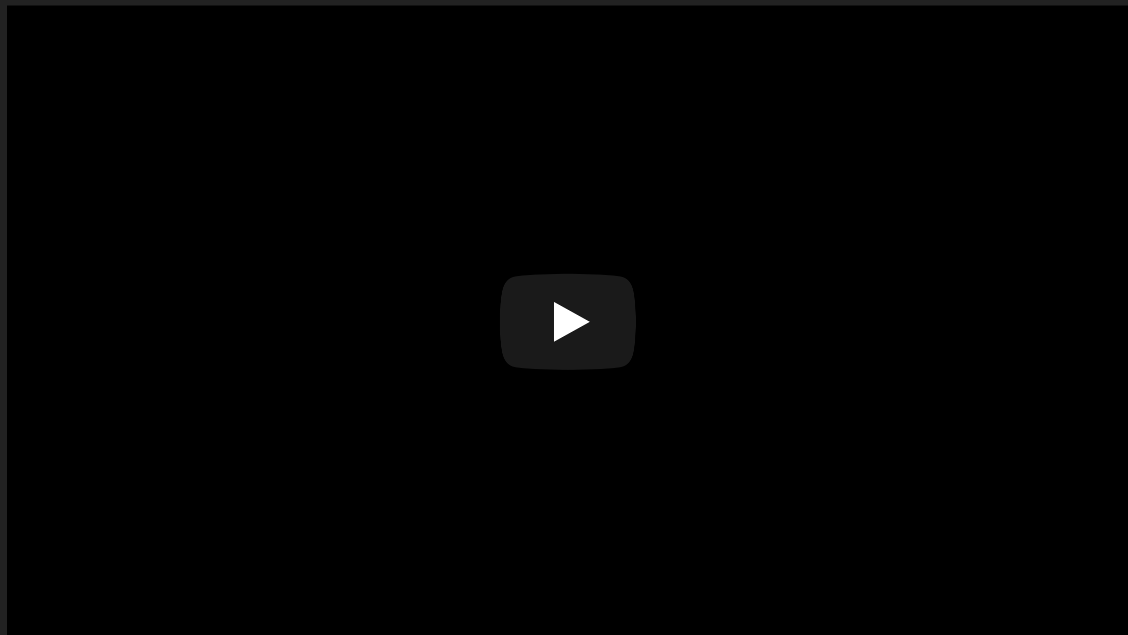
TYPES OF WAVES

- Because of the way the disturbance moves, the golf balls are pushed and pulled apart in parallel to the direction in which the disturbances are travelling. This type of propagation is known as a longitudinal wave.

TYPES OF WAVES

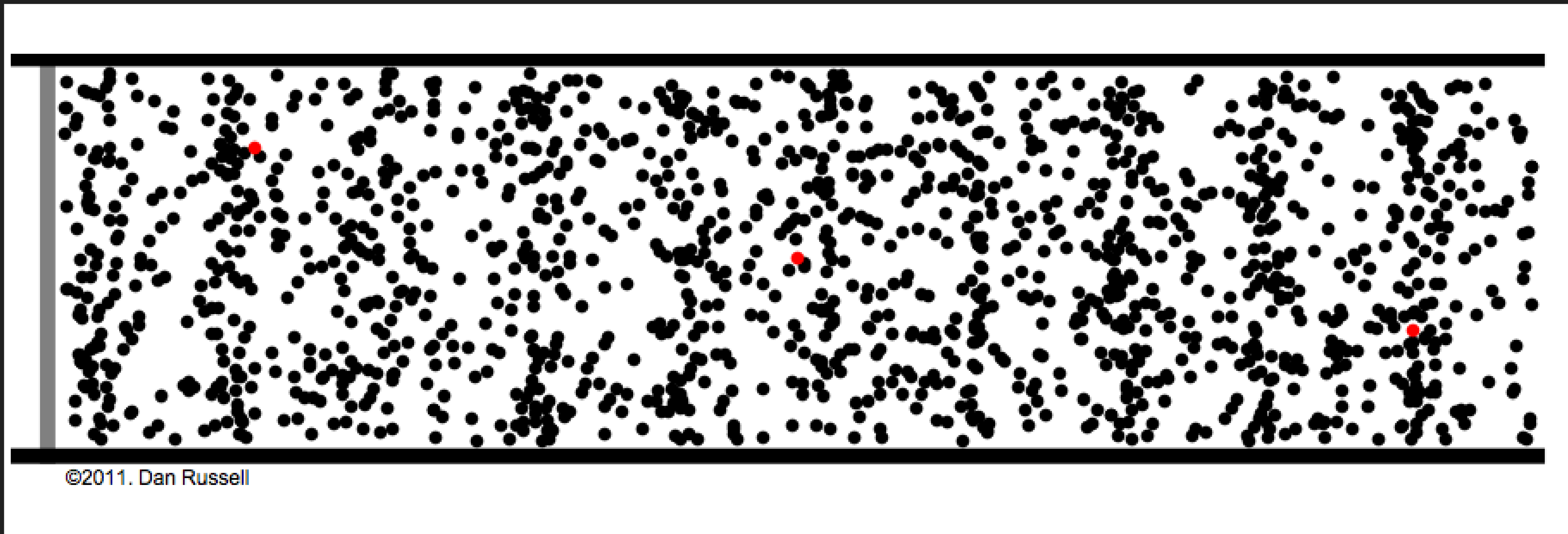
- Sound waves travel through matter in this manner, creating a series of compressions and rarefactions as they propagate in the medium.
  - Propagation: To move through, cause to move through, or transmit, especially in the form of a wave, to propagate sound.

ASIDE: VISUALISING SOUND MOVING THROUGH A MEDIUM

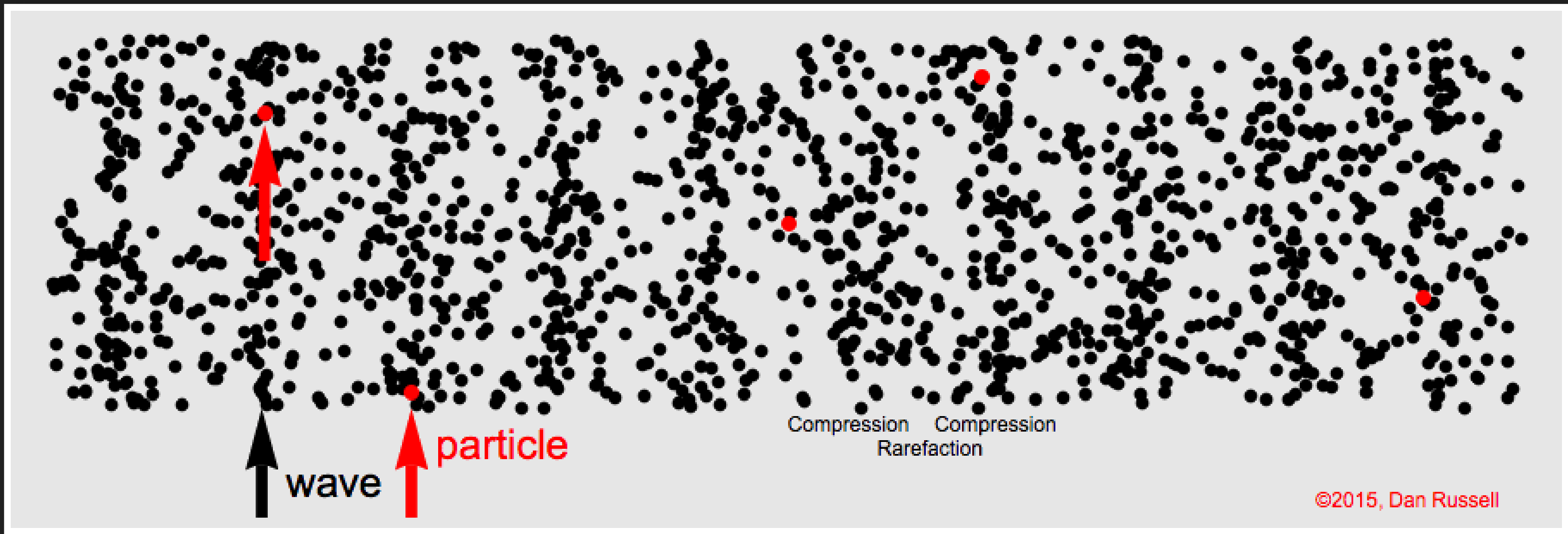


TYPES OF WAVES: LONGITUDINAL

- Longitudinal waves travel in the same direction of the movement of the particles.

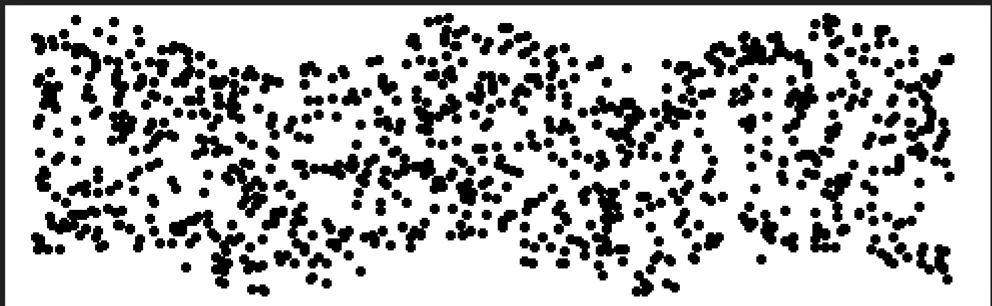


TYPES OF WAVES: LONGITUDINAL



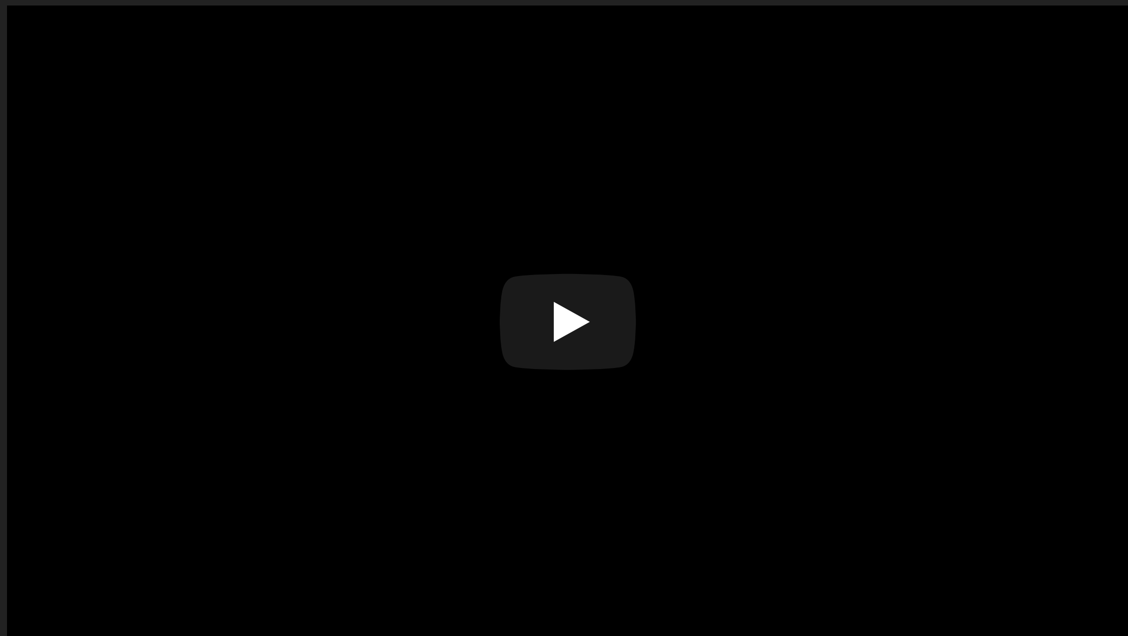
TYPES OF WAVES: TRANSVERSE

- Transverse waves travel at right angles to the movement of the particles. These occur for instance on strings and membranes so they are important for the acoustics of instruments.



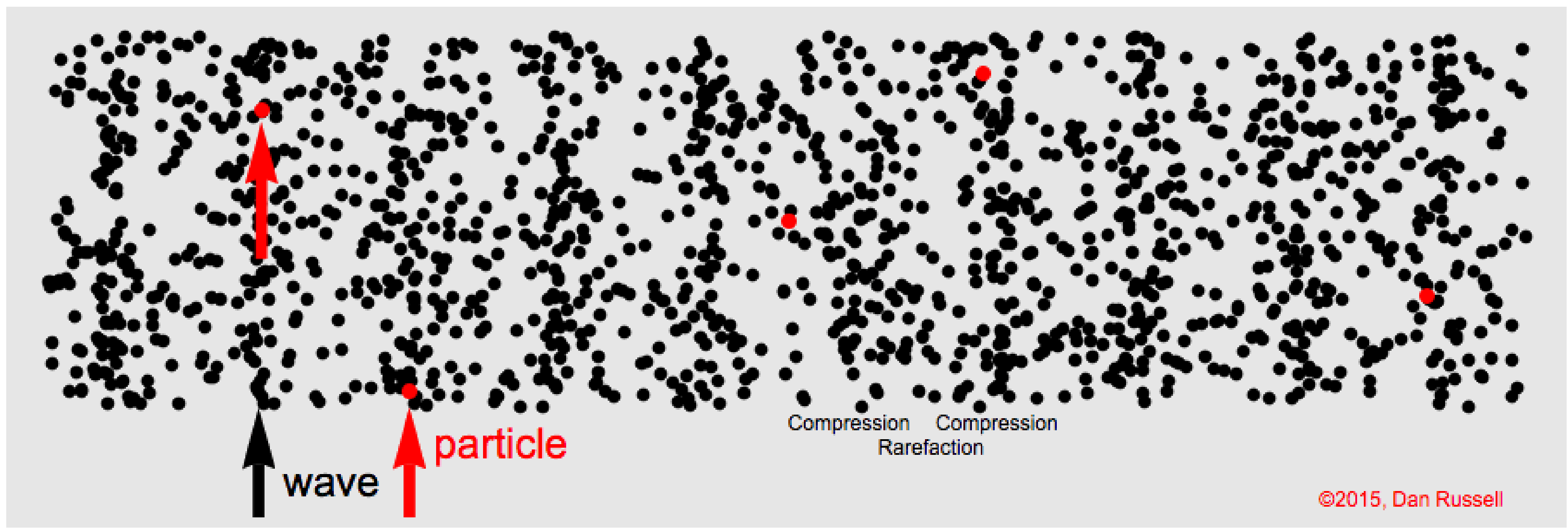
TYPES OF WAVES: TRANSVERSE

Guitar Transverse wave



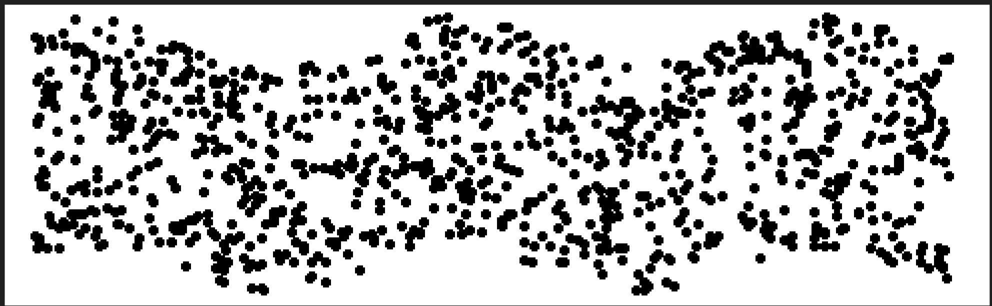
LONGITUDINAL WAVES

- Vibrations moving left and right
- Wave direction moving left or right



TRANSVERSE WAVES

- Vibrations moving up and down
- Direction of waves moving left to right or vice versa



SOUND AS ENERGY TRANSFER

- In summary, the source (e.g. voice / instrument) provides an input of energy into the medium (e.g. air), which travels through the medium, eventually reaching the receptor/listener (inner ear).
- The more energy introduced in the medium, the louder the sound (although perception is not entirely that straightforward).

SOUND AS ENERGY TRANSFER

- Attenuation is when energy is lost travelling through the medium, the intensity reduces. If the energy is totally dispersed before it reaches the receptor the chain is broken and nothing is heard.

VELOCITY OF PROPAGATION - SPEED OF SOUND

- The velocity of propagation of a sound wave is how fast the disturbance will travel.
- It depends on two factors, which are, in turn, dependent on the medium:

VELOCITY OF PROPAGATION - SPEED OF SOUND

1. Density: The larger the relation of the mass to the volume, the larger the inertia. Higher densities make the wave travel more slowly.
2. The springiness of the material: the elastic modulus. The more springy the material, the faster the wave will travel. In the golf ball and spring model, the strength of the springs.

VELOCITY OF PROPAGATION - SPEED OF SOUND

- The speed of sound in at sea level in dry air at $20°C$ is around $343 m/s$ which is equivalent to $1235 km/h$.
- For longitudinal wave in solids, the velocity is dependent on the Young's Modulus (which measures springiness) and the density.

VELOCITY OF SOUND IN SOLIDS: YOUNG'S MODULUS

- Young's Modulus: Velocity is equal to the square root of the Young's Modulus of the material divided by the density of the material.
  - $v = \sqrt{\frac{E}{\rho}}$ where v is velocity, ρ is density of the material measured in kg/m^3 and E is Young's Modulus.

VELOCITY OF SOUND IN SOLIDS: YOUNG'S MODULUS

- The density of a solid is independent of the direction of the propagation of sound in that solid. However, the Young's Modulus may be different for different directions of propagation.
- The most obvious example of this is in wood, where the direction of the grain will effect the speed of propagation in this medium. This is why loudspeaker manufacturers would use processed woods in cabinet design, so the wood has a Young's Modulus which is independent of direction.

EXAMPLE: CALCULATING THE SPEED OF SOUND THROUGH STEEL

- The density of steel is $7800kg/m^3$
- The Young's Modulus (springiness) of the steel is 2.1×10^{11}
- $v = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{2.1\times10^{11}}{7800}} = 5189m/s$
- Most of the sound that reaches us does so having travelled through air
- Air doesn't have a Young's Modulus
- What factors would affect the speed of sound in the air?

FACTORS WHICH AFFECT THE SPEED OF SOUND IN AIR

- Temperature
- Springiness and density of gas presentation
- Humidity (water vapour)
- Wind
- Air pressure

FINAL POINTS

- Sound travels more quickly in solids and liquids than in air.
- Higher density gives higher effective mass, so propagation will move more slowly but Young's Modulus offsets the increase in density. Higher figures for this imply stiff 'springs' between molecules and faster propagation.

FINAL POINTS

- Young's Modulus can change for directions of travel in irregular media (e.g. Wood). This is the reason why speaker manufacturers use processed woods, they want to avoid distortions in the output due to changes in speed of sound through the medium in various positions.