Chapter 8

8 Sound Wave Speed and Intensity 1.17.2, 1.17.3

Fundamental Concepts

- We don't hear all frequencies equally well
- Waves from point sources are spherical
- Light waves are waves in the electromagnetic field

8.1 Speed of Sound Waves

We found that waves on ropes and strings had a speed that depended on the stretchy bonds in the medium. Our equation for this is

$$v = \sqrt{\frac{T}{\mu}}$$

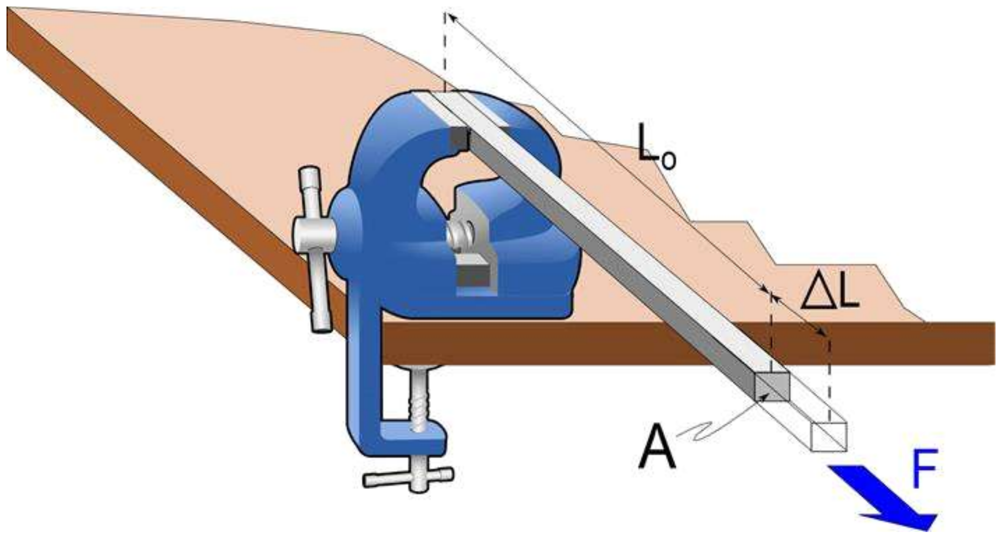
Let's think about this equation. The tension is an elastic property of the string or rope medium. And μ has the mass in it. It is an inertial property of the string or rope. It tells us how hard the string or rope is to move.

We need to have something like this for sound waves. And we know that sound waves have to do with pressure and the compression of the molecules that make up the medium. Long ago in PH121 you should have studied elastic properties of materials. But let's review them here.

8.1.1 Young's Modulus

Remember that a modulus is a constant that describes how a material can be deformed. It tells us how elastic that material is. Think of it like the spring constant k that tells us how hard it is to stretch or compress a spring.

Suppose we pull on a rod with a force $\overrightarrow{\mathbf{F}}$.



The rod will be stressed. We call this *tensile stress* which comes from a pull . This pull will stretch the solid's molecular bonds (like a tension force).

We write the stress as

$$\frac{F}{A} \tag{8.1}$$

which looks like a pressure, but this time we mean that we are pulling on the beam so that the pull is spread over the cross sectional area (marked A in the figure above). That is not much like a pressure!

By pulling on the beam, the beam will stretch. That stretching is a strain. We write the strain as the percent change in shape. In this case, the percent change in length

$$\frac{\Delta L}{L_o} \tag{8.2}$$

If the stress is not too great, then we can write a linear equation that relates the stress to the strain.

$$\frac{F}{A} = Y\frac{\Delta L}{L_o} \tag{8.3}$$

this linear equation only works in the elastic region of a stress vs. strain curve for the particular object. For example, if we pull on a pine beam we get the stress vs. strain curve in figure**??**. Our equation **??** only works for the red part marked "Elastic Region" on the curve. But this is just the region that we want to use to build buildings and airplanes and supercollider support structures, etc. We don't want to build buildings with the stress on the boards causing the boards to bend and break! So this equation is useful.

The constant of proportionality, Y, is called *Young's Modulus*. If we write this as

$$F = \frac{YA}{L_o}\Delta L \quad (8.4)$$

$$F = k\Delta L \quad (8.5)$$

it looks very much like Hook's law. Our restoring force or our "pull" is the rod pulling back with a force like $F = -k(x - x_o)$.

Young's modulus depends on the microscopic properties of the solid (which we will not study in detail, but these are our stretchy/squishy forces between atoms that make normal and tension forces). We will look up Young's modulus for each material in tables like the following:

Material[1,2]	Young's Modulus $\left(\mathrm{N/m^2}\right)$
Aluminum*	7×10^{10}
Titanium*	$11. \times 10^{10}$
Steel*	$20. \times 10^{10}$
Carbon Steel*	$21. \times 10^{10}$
Lead†	1.6×10^{10}
Brass†	$10. \times 10^{10}$
Concrete†	2.0×10^{10}
Nylon†	0.5×10^{10}
Bone† (arm or leg)	1.5×10^{10}
Pine Wood† (parallel to grain) (perpendicular to grain)	1.0×10^{10} 0.1×10^{10}

Let's take an example. Suppose we have a steel piano wire. One end of the piano wire is fixed in place, and the other is connected to a peg that can be rotated so the piano wire is tightened. This is what you do when you tune a piano, you turn the peg and tighten the wire. Suppose we tighten the wire so that there will be 980 N of tension on the wire. The wire is 1.6 m long and has a diameter of 2 mm. How much will the wire stretch as we tighten the peg? We will need to know that the Young's modulus for steel is $20 \times 10^{10}\,\mathrm{N/m^3}$.

Here is a summary of what we know

$$\begin{aligned} T &= 980\,\mathrm{N} \\ L_o &= 1.6\,\mathrm{m} \\ d &= 2\,\mathrm{mm} \\ Y &= 200 \times 10^9\,\mathrm{N/m^2} \end{aligned}$$

[1] *Ledbetter, H. M., Physical Properties Data Compilations Relevant to Energy Storage, US National Bureaus of Standards, 1982. Different alloys have different properties, so for any real work see the original tables in the original publication.

[2] †Average values from numbers given in various text books. These numbers should be taken as example values and more exact numbers found for any real work.

Let's start with our stress/strain basic equation

$$\frac{F}{A} = Y\frac{\Delta L}{L_o}$$

and solve for ΔL

$$\frac{F}{A}\frac{L_o}{Y} = \Delta L$$

the force is our tension, and the cross sectional area will be

$$A = \pi\frac{d^2}{4}$$

$$\frac{T}{\pi\frac{d^2}{4}}\frac{L_o}{Y} = \Delta L$$

$$\frac{4T}{\pi d^2}\frac{L_o}{Y} = \Delta L$$

then

$$\begin{aligned}\Delta L &= \frac{4\,(980\,\mathrm{N})}{\pi\,(2\,\mathrm{mm})^2}\frac{(1.6\,\mathrm{m})}{(200\times 10^9\,\mathrm{N/\,m^2})} = \\ &= 2.4955\times 10^{-3}\,\mathrm{m}\end{aligned}$$

so the wire stretched about a quarter of a centimeter.

Now that we remember what a modulus is, let's consider the speed of sound in our bar of metal. Say, we hit the bar with a hammer. Sound waves would be created in the bar. But suppose we make our bar thin and stretch it across a guitar. Now as we hit the string we expect a wave. We need a measure of the elasticity of the metal and a measure of the inertial of the metal material. The tension in the (now) wire would be our force

$$\begin{aligned}v &= \sqrt{\frac{T}{\mu}} = \sqrt{\frac{Y\frac{\Delta L}{L_o}A}{\frac{m}{L_o}}} \\ &= \sqrt{\frac{Y\Delta LA}{m}} \\ &= \sqrt{\frac{Y\cancel{V}}{m}} \\ &= \sqrt{\frac{Y}{\rho}}\end{aligned}$$

And we have the wave speed in terms of the an elastic quantity (Young's modulus) and an inertial property (the metal density). This gives a wave speed of

$$v = \sqrt{\frac{Y}{\rho}}$$

But this won't do for sound waves in air. We need a different modulus for gasses.

8.1.2 Bulk Modulus

This one is harder. It tells us how much a solid can be squashed or, compressed. Let's define

$$\Delta P = \frac{\Delta F}{A} \tag{8.6}$$

where now A is the outer surface area of the solid. If we were dealing with a fluid, this would be pressure. Often fluids are very hard to compress (we assumed they were not at all compressible). Many solids are easy to compress. Think of Styrofoam or any foam rubber. For solids $\Delta F/A$ where the force is all around the solid and the area is the surface area is a stress. The strain is the percentage change in volume (change amount over the original volume)

$$\frac{\Delta V}{V} \tag{8.7}$$

and the relationship is

$$\Delta P = -B\frac{\Delta V}{V} \tag{8.8}$$

B is the *bulk modulus*, which again, we look up in tables.

Material[3]	Bulk Modulus $\left(\mathrm{N/m^2}\right)$
Steel‡	140×10^9
Cast Iron‡	90×10^9
Brass‡	80×10^9
Aluminum‡	70×10^9
Water‡	2×10^9
Ethyl Alcohol‡	1×10^9
Mercury‡	2.5×10^9
Air‡	1.01×10^5

The minus sign may be surprising. But in our definition of bulk modulus, we are thinking of compression. So usually ΔV is negative. The minus sigh means that for compression this formula gives positive values. Also notice that there is a ΔP or ΔF in our formula. Usually we start compressing a solid while it is experiencing air pressure. So we don't start from zero stress. We change the force from the force due to air pressure to some larger compressive force.

Once again we have a quantity that shows how elastic our medium is, B. And we can still use the density for the inertial property of the gas, ρ. So our speed of sound in a gas is

$$v = \sqrt{\frac{B}{\rho}}$$

[3] ‡Average values from numbers given in various text books. These numbers should be taken as example values and more exact numbers found for any real work.

But how do we find B? That is something we will do much later in this course. So for now let's borrow a result from our future. For an ideal gas

$$v = \sqrt{\frac{\gamma R T_K}{M}}$$

where γ is the adiabatic index (related to the type of gas we have) and R is the universal gas constant, and T_K is the temperature in kelvins and M is the gas molar mass. For now we can just use this approximation.

This might not be exactly clear at this point. But what is important is that the speed changes with temperature. The hotter the gas, the faster the waves. If we assume the air is like an ideal gas, this reduces to just

$$v = v_o\sqrt{1 + \frac{T_c}{T_o}} \tag{8.9}$$

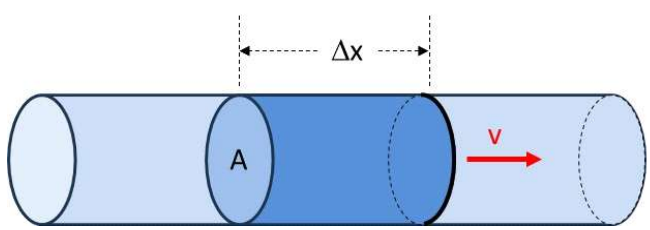
where $v_o = 331\,\frac{\mathrm{m}}{\mathrm{s}}$ and $T_o = 273\,\mathrm{K}$ ($0\,^\circ\mathrm{C}$).[4]

The speed of sound in air at normal room temperature is around $340\,\mathrm{m/s}$.

8.1.3 Finding the speed of sound in air @@@@ Don't do this here! @@@@@

Now that we know about adiabatic processes, let's go back to the beginning of our course and think about the speed of sound in air. The disturbance that makes the wave will change the pressure and compress the gas a bit. So work will be done on the gas. But the disturbance happens quickly and we wouldn't expect energy transfer by heat. This is an adiabatic process!

We used pipes when we studied sound waves. So, let's consider our air in a pipe.



The pipe has a cross sectional area, A. And let's look at a small volume of air in the pipe. The darker region is our small volume of air and let's say it has a mas Δm where here the delta means "a small amount of" and not a difference. The density of the air is given by

$$\rho = \frac{\Delta m}{\Delta \mathcal{V}}$$

[4] $v = v_o\sqrt{1 + \frac{T_C}{T_o}} = v_o\sqrt{\frac{T_o}{T_o} + \frac{T_C}{T_o}} = v_o\sqrt{\frac{T_o + T_C}{T_o}} = v_o\sqrt{\frac{T_K}{T_o}}$

so we can write

$$\Delta m = \rho \Delta \forall$$

But look at our little mass' volume

$$\forall = A\Delta x$$

so we can write Δm as

$$\Delta m = \rho A \Delta x$$

Now let's consider the amount of mass that passes a point in our pipe. That is our mass flow rate and we know that is

$$\frac{dm}{dt}$$

If we make our small amount of mass very small, we would have

$$dm = \rho A dx$$

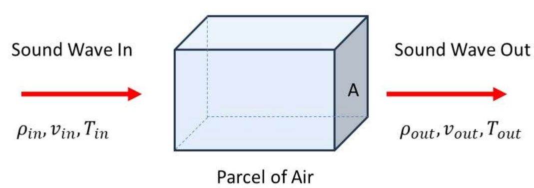
and our mass flow rate would be

$$\frac{dm}{dt} = \frac{\rho A dx}{dt} = \rho A v$$

This looks familiar. It is one side of our equation of continuity

$$\rho_{in} A_{in} v_{in} = \rho_{out} A_{out} v_{out}$$

Now consider a "parcel of air." This is just a part of the air that we will pay attention to. It is surrounded by more air and is only different because we are thinking about it. But concert such a parcel of air and let's make it sort of box shaped like in the next figure.



We could write $\rho_{in} = \rho$ and $v_{in} = v$ and $T_{in} = T$ and we could write $\rho_{out} = \rho + d\rho$, $v_{out} = v + dv$, and $T_{out} = T + dT$. Let's put these in our continuity equation.

$$\rho A v = (\rho + d\rho) A (v + dv)$$

The area, A, didn't change. So it cancels, and we can do some algebra

$$\begin{aligned}\rho v &= (\rho + d\rho)(v + dv) \\ \rho v &= \rho v + \rho dv + v d\rho + d\rho dv\end{aligned}$$

We can assume that $d\rho$ will be small if our parcel of air isn't too big. And likewise dv will be small. So $d\rho dv$ should be very small. Let's drop this term.

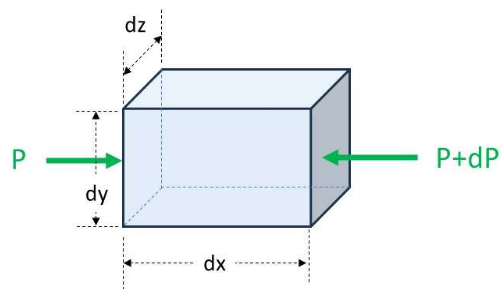
$$\rho v = \rho v + \rho dv + v d\rho$$

and the ρv terms cancel

$$0 = \rho dv + v d\rho$$

$$\rho dv = -v d\rho \tag{8.10}$$

This doesn't seem to have helped, but we will use it later. Let's go back to our parcel of air and this time think of the forces on the input and output sides.



We will have an input pressure and an output pressure with $P_{in} = P$ and $P_{out} = P + dP$

We remember that $F = PA$ so we will have a force on the input side

$$F_{in} = P_{in}A = PA = Pdydz$$

and an output force

$$F_{out} = -P_{out}A = -(P + dP)\, dydz$$

The net force would be

$$\begin{aligned} F_{net} &= Pdydz - Pdydz - dPdydz \\ &= -dPdydz \end{aligned}$$

Then

$$ma = -dPdydz$$

We can divide by the mass to get the acceleration

$$a = -\frac{dPdydz}{m}$$

and now think,

$$\rho = \frac{m}{\cancel{V}} = \frac{m}{dxdydz}$$

so

$$m = \rho dxdydz$$

so our acceleration is

$$\begin{aligned} a &= -\frac{dPdydz}{\rho dxdydz} \\ &= -\frac{dP}{\rho dx} \end{aligned}$$

and $a = dv/dt$

$$\frac{dv}{dt} = -\frac{dP}{\rho dx}$$

$$dv = -\frac{dPdt}{\rho dx}$$

and recall that $v = dx/dt$

$$dv = -\frac{dP}{\rho v}$$

or

$$dv\rho v = -dP$$

Finely we can use our result from our continuity equation (8.10) $\rho dv = -vd\rho$

$$\begin{aligned} v\rho dv &= -dP \\ v\left(-vd\rho\right) &= -dP \\ v\left(-vd\rho\right) &= -dP \\ v^2 &= \frac{dP}{d\rho} \end{aligned}$$

and we are close. the wave speed, v, is the square root of the pressure change over the density change.

$$v = \sqrt{\frac{dP}{d\rho}} \tag{8.11}$$

This is a little like $\sqrt{B/\rho}$. So we are close.

Since we are modeling this as an adiabatic process we know

$$P\not{V}^{\gamma} = \text{constant}$$

Let's look at that volume, $\not{V}$.

$$\not{V} = \frac{m}{\rho}$$

and we can write the mass, m, in terms of the molar mass

$$M = \frac{m}{n}$$

or

$$m = nM$$

so our volume is

$$\cancel{V} = \frac{nM}{\rho}$$

and let's put this into our adiabatic process equation

$$P\cancel{V}^{\gamma} = P\left(\frac{nM}{\rho}\right)^{\gamma} = \text{constant}$$

we could write this as

$$P\frac{n^{\gamma}M^{\gamma}}{\rho^{\gamma}} = \text{constant}$$

and rearrange it to be

$$P\frac{1}{\rho^{\gamma}} = \frac{\text{constant}}{n^{\gamma}M^{\gamma}}$$

and since n and M are not changing

$$P\frac{1}{\rho^{\gamma}} = \text{new constant}$$

Let's take the logarithm of both sides

$$\begin{aligned} \ln\left[P\frac{1}{\rho^{\gamma}}\right] &= \ln\left[\text{new constant}\right] \\ \ln P - \gamma \ln \rho &= \ln\left[\text{new constant}\right] \\ \ln P - \gamma \ln \rho &= \text{another new constant} \end{aligned}$$

Now let's take the derivative of both sides

$$\frac{d}{d\rho}\left(\ln P - \gamma \ln \rho\right) = \frac{d}{d\rho}\left(\text{another new constant}\right)$$

The right hand side is just zero (which is why we didn't spend time figuring out the number for the constant!).

$$\frac{d}{d\rho}\left(\ln P - \gamma \ln \rho\right) = 0$$

But the right hand side gives

$$\begin{aligned} \frac{1}{P}\frac{dP}{d\rho} - \frac{\gamma}{\rho}\frac{d\rho}{d\rho} &= 0 \\ \frac{1}{P}\frac{dP}{d\rho} &= \frac{\gamma}{\rho} \\ \frac{dP}{d\rho} &= \frac{\gamma}{\rho}P \qquad (8.12) \end{aligned}$$

Now let's pretend that the air is an ideal gas. Then we know that

$$\begin{aligned} PV &= nRT \\ &= \frac{m}{M}RT \end{aligned}$$

and we can solve for P and put it into equation (8.12)

$$\begin{aligned} P &= \frac{m}{VM}RT \\ &= \frac{\rho}{M}RT \end{aligned}$$

and then equation (8.12 becomes

$$\frac{dP}{d\rho} = \frac{\gamma}{\rho}\frac{\rho}{M}RT = \frac{\gamma}{M}RT \tag{8.13}$$

and we can put this directly into equation (8.11)

$$v = \sqrt{\frac{dP}{d\rho}} = \sqrt{\frac{\gamma}{M}RT}$$

We can get our approximation that we used earlier for temperature dependence for sound speed in air from putting in some numbers. First, let's define $T_o = 273\,\mathrm{K}$. Then

$$\begin{aligned} v &= \sqrt{\frac{\gamma}{M}RT\frac{T_o}{T_o}} \\ &= \sqrt{\frac{\gamma RT_o}{M}}\sqrt{\frac{T}{T_o}} \end{aligned}$$

It turns out that for air at normal air pressure and at $T = 10\,^\circ\mathrm{C}$, $\gamma = 1.4$ and $M = 0.02897\frac{\mathrm{kg}}{\mathrm{mol}}$, and of course $R = 8.31\frac{\mathrm{J}}{\mathrm{mol\,K}}$ then our speed is

$$\begin{aligned} v &= \sqrt{\frac{(1.4)\left(8.31\frac{\mathrm{J}}{\mathrm{mol\,K}}\right)(273\,\mathrm{K})}{0.02897\frac{\mathrm{kg}}{\mathrm{mol}}}}\sqrt{\frac{T}{T_o}} \\ &= 331.1\frac{\mathrm{m}}{\mathrm{s}}\sqrt{\frac{T}{T_o}} \\ &= 331.1\frac{\mathrm{m}}{\mathrm{s}}\sqrt{\frac{T}{273\,\mathrm{K}}} \end{aligned}$$

where T is in kelvins. We can change this to having T in Celsius if we

$$\begin{aligned} v &= 331.1\frac{\mathrm{m}}{\mathrm{s}}\sqrt{\frac{T_o + T_c}{T_o}} \\ &= 331.1\frac{\mathrm{m}}{\mathrm{s}}\sqrt{1 + \frac{T_c}{T_o}} \end{aligned}$$

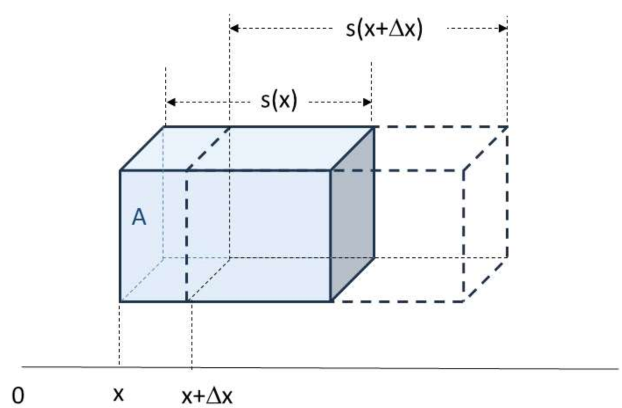
which is what we used before.

8.2 Intensity of Sound Waves @@ Maybe do this

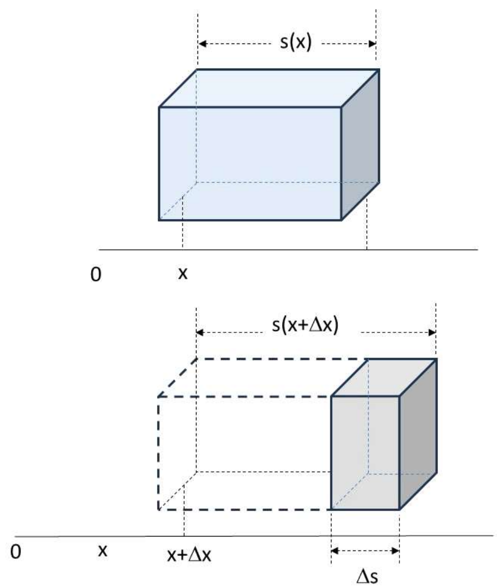
We have already learned that knowing the power of a sound source isn't enough to tell us how loud that sound source will appear to us. We know the sound gets's spread out over a big spherical area. And we use the quantity called intensity to describe how spread out the power is at a particular distance.

$$\mathcal{I} = \frac{\mathcal{P}}{4\pi r^2} \tag{8.14}$$

Let's consider a parcel of air. The air might both move and stretch as the sound wave passes. So the displacement from equilibrium $s(x)$ might be different as the air moves to location $x + \Delta x$. The next figure tries to show this.



Let's look at the stretch of the parcel of air for a moment. Let's take the before size of the parcel of air and compare it to the stretched parcel size.



We can see that the size difference for the displacement from equilibrium is

$$\Delta s = s\left(x + \Delta x\right) - s\left(x\right)$$

The change in volume would be

$$\Delta \cancel{V} = A \Delta s$$

The fractional change in volume is defined as

$$\frac{\Delta \cancel{V}}{\cancel{V}}$$

and we can see that this will be

$$\frac{\Delta \cancel{V}}{\cancel{V}} = \frac{A \Delta s}{A \Delta x} = \frac{\Delta s}{\Delta x}$$

If we take the limit as $\Delta x \rightarrow 0$ this is just

$$\frac{d\cancel{V}}{\cancel{V}} = \frac{ds}{dx}$$

Now let's go back to our bulk modulus, B. A form for the bulk modulus is

$$B = -\frac{\Delta P}{d\cancel{V}/\cancel{V}}$$

We can solve this for ΔP

$$\Delta P = -B \frac{d\cancel{V}}{\cancel{V}} = -B \frac{ds}{dx}$$

For a sinusoidal wave,

$$s(x,t) = s_{\max} \sin(kx - \omega t + \phi_o) \tag{8.15}$$

(where ϕ_o could be $\pi/2$ to make this really a cosine).and we can take a derivative of this

$$\frac{ds}{dx} = -ks_{\max} \cos(kx - \omega t + \phi_o)$$

then

$$\Delta P = -B\frac{ds}{dx} = Bks_{\max} \cos(kx - \omega t + \phi_o)$$

We want the intensity and the intensity is

$$\mathcal{I} = \frac{\mathcal{P}}{A} \tag{8.16}$$

We could write the power as the force multiplied by the velocity

$$\mathcal{I} = \frac{Fv}{A} = Pv \tag{8.17}$$

We know something about the pressure, we need the speed. But this is the speed of parts of the medium. And we know how to find that for waves.

$$v(x,t) = \frac{d}{dt}s(x,t) = -\omega s_{\max} \cos(kx - \omega t + \phi_o)$$

We can put this all together to get the intensity

$$\begin{aligned}
\mathcal{I} &= \Delta P v \quad (8.18)\\
&= (Bks_{\max} \cos(kx - \omega t + \phi_o))(-\omega s_{\max} \cos(kx - \omega t + \phi_o)) \quad (8.19)\\
&= -Bk\omega s_{\max}^2 \cos^2(kx - \omega t + \phi_o) \quad (8.20)
\end{aligned}$$

The intensity is proportional to the amplitude of the displacement, $s_{\max}$ squared.

We often can only measure a time average intensity. To average our intensity function over one period we would integrate

$$\begin{aligned}
\langle \mathcal{I} \rangle &= \int_0^T -Bk\omega s_{\max}^2 \cos^2(kx - \omega t + \phi_o)\\
&= -Bk\omega s_{\max}^2 \int_0^T \cos^2(kx - \omega t + \phi_o)\, dt\\
&= -Bk\omega s_{\max}^2 \frac{1}{2}
\end{aligned}$$

With a little more math we can write this in terms of $\Delta P_{\max} = Bks_{\max}$

$$\begin{aligned}
\langle \mathcal{I} \rangle &= -\frac{Bk\omega s_{\max}^2}{2} = -\frac{\omega}{2}(Bks_{\max})(s_{\max})\\
&= -\frac{\omega}{2}(Bks_{\max})\left(\frac{Bks_{\max}}{Bk}\right)\\
&= -\frac{\omega}{2}(\Delta P_{\max})\left(\frac{\Delta P_{\max}}{Bk}\right)\\
&= -\frac{\omega}{2Bk}(\Delta P_{\max})^2
\end{aligned}$$

and we know for sound the wave speed is given by

$$v = \frac{\omega}{k} = \sqrt{\frac{B}{\rho}}$$

so

$$B = \frac{\omega^2}{k^2}\rho$$

$$\langle \mathcal{I} \rangle = -\frac{\omega}{2\left(\frac{\omega^2}{k^2}\rho\right)k}\left(\Delta P_{\max}\right)^2$$

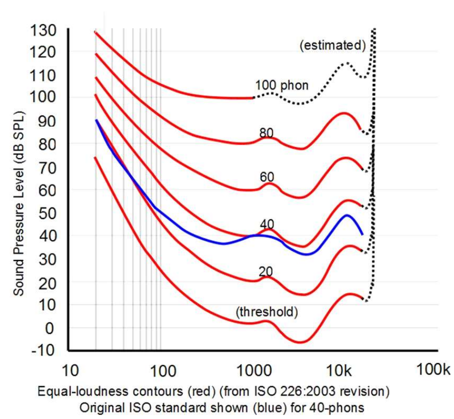
$$\langle \mathcal{I} \rangle = -\frac{1}{2\left(v\rho\right)}\left(\Delta P_{\max}\right)^2$$

This gives us the average intensity in the pressure picture for sound waves and once again the intensity is proportional to the amplitude squared.

8.3 Sound Levels in Decibels

The intensity of a sound wave gives us how much power per unit area is being delivered by the wave. This is a great way to measure the power delivered by a sound wave because most instruments have a detection area. So power per unit area is a natural measurement for instruments.

Frequency Range Demo



Robinson-Dadson equal loudness curves (Image in the Public Domain courtesy Lindosland)

but our ears are not designed to be quantitative scientific instruments (though they are truly amazing in their range and ability). Sounds with the same intensity at different frequencies do not appear to us to have the same loudness.

The frequency response graph above shows how this relationship works for test subjects[5].

Our Design Engineer made an interesting choice in building us. We need to hear very faint sounds, and very loud sounds too. In order to make us able to hear the soft sounds without causing extreme discomfort when we hear the loud, He gave up linearity. That is, we don't hear twice the sound intensity as twice as loud.

The mathematical expression that matches our perception of loudness to the intensity is

$$\beta = 10\log_{10}\left(\frac{I}{I_o}\right) \tag{8.21}$$

Sound Meter Demo

where the quantity I_o is a reference intensity.

We call β the *sound level*. The quantity I_o we choose to be the *threshold of hearing*,

$$I_o = 1\times 10^{-12}\,\frac{\mathrm{W}}{\mathrm{m}^2}$$

the intensity that is just barely audible for humans (it will be different for electronic devices or other animals). Measured this way, we say that intensity is in units of decibels (dB).The decibel, is useful because it can describe a non-linear response in a linear way that is easy to match to our human experience. But it is tricky because, like radians, it is dimensionless because we are comparing two intensities (I/I_o). We expect the same strange unit behavior with dB that we see with radians.

Suppose we double the intensity by a factor of 2.

$$\begin{aligned}\beta &= 10\log_{10}\left(\frac{2I_o}{I_o}\right)\\ &= 10\log_{10}2\\ &= 3.0103dB\end{aligned}$$

The sound intensity level is not twice as large, but only $3dB$ larger. It is a tiny increase. This is what we hear. A good rule to remember is that $3dB$ corresponds to a doubling of the intensity.

The tables that follow give some common sounds in units of dB and $\mathrm{W/m^2}$. Just for reference, I have measured a Guns n Roses concert at 120 dB outside the stadium.

[5] Ones that have not gone to Guns n Roses concerts

Sound	Sound Level (dB)
Jet Airplane at 30m	140
Rock Concert	120
Siren at 30m	100
Car interior when Traveling 60mi/hr	90
Street Traffic	70
Talk at 30cm	65
Whisper	20
Rustle of Leaves	10
Quietest thing we can hear (Io)	0