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## Physics, Physiology and Psychology

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When we complain about intrusive noise, sooner or later we encounter the word decibel. Typically what happens is that some official comes along and mumbles something about decibels and then explains to the authorities that the noise we are complaining about isn't really all that loud at all. He will say something about logarithms, which municipal council members don't understand at all but will be impressed by the long words, and your complaint is dismissed.

I have suffered through this process, and I have had to listen to a professional acoustical engineer spouting jargon to a municipal council, and the council swallowing everything he says. What makes it all the more annoying for me is that I am by profession a research physicist and I have had to sit through technical evidence that is to me manifest scientific nonsense.

One apparently common misconception (deliberate or otherwise I know not), is that an increase of 10 decibels corresponds to only a doubling of perceived loudness. I have heard an engineer give evidence to this effect to a municipal council, and it is repeated, quite erroneously, in the Harvard Medical School Health Letter article "Noise Pollution: Irritant or Hazard" which has been distributed by our own Society. I have from time to time had occasion to teach physics to medical students, and I can tell you that it is a rather discouraging experience! The problem with this particular myth is that we are told that the "perceived loudness" of, say 60 decibels is not all that much louder than, say, 55 decibels. We need to put this straight.

Another problem is that we are often told that 55 dB is about the level of normal conversation and is therefore nothing to complain about. Again, we need to put this straight.

This article will be technical where need be, and I shall not avoid equations when necessary. Not everyone will understand the more technical and mathematical bits. But I feel that it is very important to put it on record correctly and in a manner that can be understood at a scientific level. To avoid this would mean trying to argue scientific matters by polemics rather than by reason. In any case I am sure that most members will follow most of the article and are capable of skipping over the mathematical bits.

The problem of how loud a sound is, or is perceived to be, or how annoying it is, can be discussed from the points of view of physics, or of physiology, or of psychology. I am going to take each of these in turn. Of these, believe it or not, it is physics that is easiest!

In physics it is possible to specify and measure a sound level with great precision, and the decibel scale has its basis in good physics. Sound is a form of energy, and energy is expressed in a very precise unit called the joule. The sound intensity arriving at your dwelling can be very precisely measured in terms of the rate of arrival of energy across unit area, and is expressed in joules per second per square metre. There is nothing at all subjective about it. Nor does it depend on the frequency of the sound wave.

The decibel scale is used to express the ratio of a particular sound intensity to some standard, usually taken to be an intensity of  $1.E-12$  joules per second per square metre. (Sorry for the technicality there, but we must put it on record in precise terms.) The scale is such that if one sound has TEN times (NOT twice!) the intensity of another, the difference in sound levels is said ten decibels, or 10 dB. Those familiar with logarithms will understand (and those unfamiliar will be mystified!) that a factor of two in sound intensity corresponds to a difference of THREE (NOT ten!) decibels.

In summary: 53 dB is twice the sound intensity of 50 dB, 60 dB is ten times the sound intensity of 50 dB.

And do not let anyone tell you otherwise!!!!

We now move on to a science a little less precise than physics, namely physiology. The ear is not equally sensitive to all frequencies, and entirely insensitive to very high and very low frequencies. The frequency response of the ear varies from individual to individual, and especially it varies with age, and it also varies with the intensity of the sound. The relative sensitivity of the ear to different frequencies can be measured (somewhat subjectively) by asking an individual to compare two sounds of different frequencies, and by varying the intensity of one sound until the subject judges them to be equally loud. Thus we can measure something that might be called "perceived loudness", which is not the same thing as sound intensity; it does depend on the sound intensity, but it also depends on the frequency spectrum.

In order to allow for the properties of the human ear, a "dBA" scale, or "decibels on the A scale" has been set up, in which a decibel meter is set up to imitate as closely as possible the frequency sensitivity of the human ear. This varies from human to human; however, the dBA scale is set up in reference to a "standard" human ear, whose frequency sensitivity is in fact precisely defined, even if it may not coincide exactly with your own ear. Thus the dBA scale, even though intended to imitate a sort of average human ear, is quite precisely defined in the sense that the sound intensity on the dBA scale is not a matter of opinion but it is capable of almost as precise definition and measurement as a frequency-independent scale.

I have seen no justification in any scientific literature of the common statement that "perceived loudness" doubles for every increase of ten on the dBA scale. I have seen this incorrect statement accompanied by an explanation that perceived loudness is proportional to the logarithm on the sound intensity. I first heard these assertions given in evidence to a municipal council by an engineer who was attempting to convince the council that 60 dB wasn't all that much louder than 55 dB, and that my complaints about noise were unjustified. In fact the engineer was merely displaying his ignorance of elementary logarithms at a high school level, for both statements cannot possibly be true. If it were indeed so that 10 dB results in only a two-fold increase in perceived loudness, it does not mean that perceived loudness is proportional to the logarithm of the intensity. It would mean that the perceived loudness is proportional to the intensity to the power of 0.3. This may sound very technical, but it is important to put it on record, because we who are disturbed by noise are often portrayed as ignorant and it needs an engineer to come along and make some measurements and talk about logarithms and decibels to prove that we really aren't disturbed by the noise at all!

In fact one of the reasons that the decibel scale was first set up was to accommodate a physiological "law" known as the Weber-Fechner law, in which it was supposed that perceived loudness was proportional to the logarithm of the intensity; or, put another way, if the sound intensity increases geometrically, the perceived loudness increases arithmetically. According to

this law, the perceived loudness would be linearly proportional to the decibel scale. The Weber-Fechner law is, however, only a rather approximate rule of thumb rather than a physical law, although it is fairly good over a moderate range of intensities. No very simple mathematical expression exists, for accurately describing perceived loudness over a wide range of frequencies and intensities, and there is no basis at all for the "doubling for every 10 dB". What cannot be denied, however, is that sound intensity, if not perceived loudness, increases tenfold for every 10 dB.

We have seen, then, that from the point of view of physics, the decibel scale is perfectly well defined. From the point of view of physiology, the "dBA" scale has been set up to approximate the response of the human ear. The third word in our title was psychology, and this deals with how annoying or disturbing a sound actually is. Psychology is the least amenable to quantification of the three sciences in the title. It is barely possible to set up a mathematical scale to determine how annoying a particular noise is, and indeed from this point of view the engineer's measurements of decibels and his learned if erroneous talk of logarithms is largely irrelevant. For example, it is sometimes held that normal conversation is about 58 dB and a noise at this level is therefore nothing to complain about. Indeed Saanich Municipality on this basis allows 58 decibels continuously from 9 a.m. to 10 p.m. at my property on this very basis that 58 dB is "only" normal conversation and is not harmful and it is therefore unreasonable to complain about. But try yourself to hold a conversation with someone, or to read a book or to watch television, or to study or to go to sleep when someone is unceasingly making a noise at 58 dB! Such an unwanted intrusion is utterly intolerable, and it is no answer at all to say it is "only" 58 dB and is not "harmful".

We can give many very simple and ridiculously obvious examples to show that the decibel scale gives no indication at all as to how annoying or disturbing an unwanted noise can be. We have seen above that 58 dB is twice the sound intensity of 55 dB. Does it follow that 58 dB is twice as annoying? Not a bit of it! Consider the following examples.

(1) Which is the more annoying:

- (a) 58 dB for five seconds? or
- (b) 55 dB for five hours?

(2) Which is the more annoying:

- (a) 58 dB at 3:00 p.m.? or
- (b) 55 dB at 3:00 a.m.?

(3) Which is the more annoying:

- (a) a Mozart piano sonata at 58 dB?
- (b) someone scraping his fingernails over a blackboard at 55 dB?

These absurdly simple examples demonstrate clearly that the amount of annoyance a noise causes is not to be measured by decibels or by engineers, and we must not allow "authorities" to tell us that we are not annoyed by some noise because the decibel reading proves that we are not annoyed.

This is an important point, because there are generally two types of municipal noise bylaw. In one, it is deemed to be an offence to make a noise that causes disturbance to persons. In the other, it is deemed to be an offence to make a noise that exceeds a certain decibel level. It is often held that the latter type of bylaw is more "scientific" and more "objective" and

hence more desirable. In a future article I shall argue very strongly against this viewpoint and I would warn very strongly about accepting a bylaw that sets a decibel level rather than one which prohibits disturbance.

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