dB and Amplitude

I. LOUNDNESS, INTENSITY AND AMPLITUDE

Just as there is a relation between frequency and the musically important quality called pitch, there is also a relation between the intensity of the sound as measured by the amount of energy delivered by the sound wave to ears, and the loundness of the sound as preceived by people. Just as the relation between pitch and frequency is an unexpected multiplicative relation, so there is also a multiplicative relation between loudness and intensity of the sound.

However, in the case of pitch, there is a standard set by the octave. Most humalns preceive the relation of an octave as special, as being almost an equivalence. Two instruments or singers singing an octave apart blend together and seem to be almost the same. One does not feel that a bass and a soprano singing the same tune but say two octaves apart are singing different notes.

In the case of loudness there is no such standard. So instead physicists have set up a standard called the Bel, or more commonly the deci-Bel (usually written as dB).

The Bel is defined such that if one sound is ten times as intense, delivers 10 times the energy to the ear, then that sound is defined to one Bel louder. If a sound is 100 times as intense, it is 2 Bel louder.

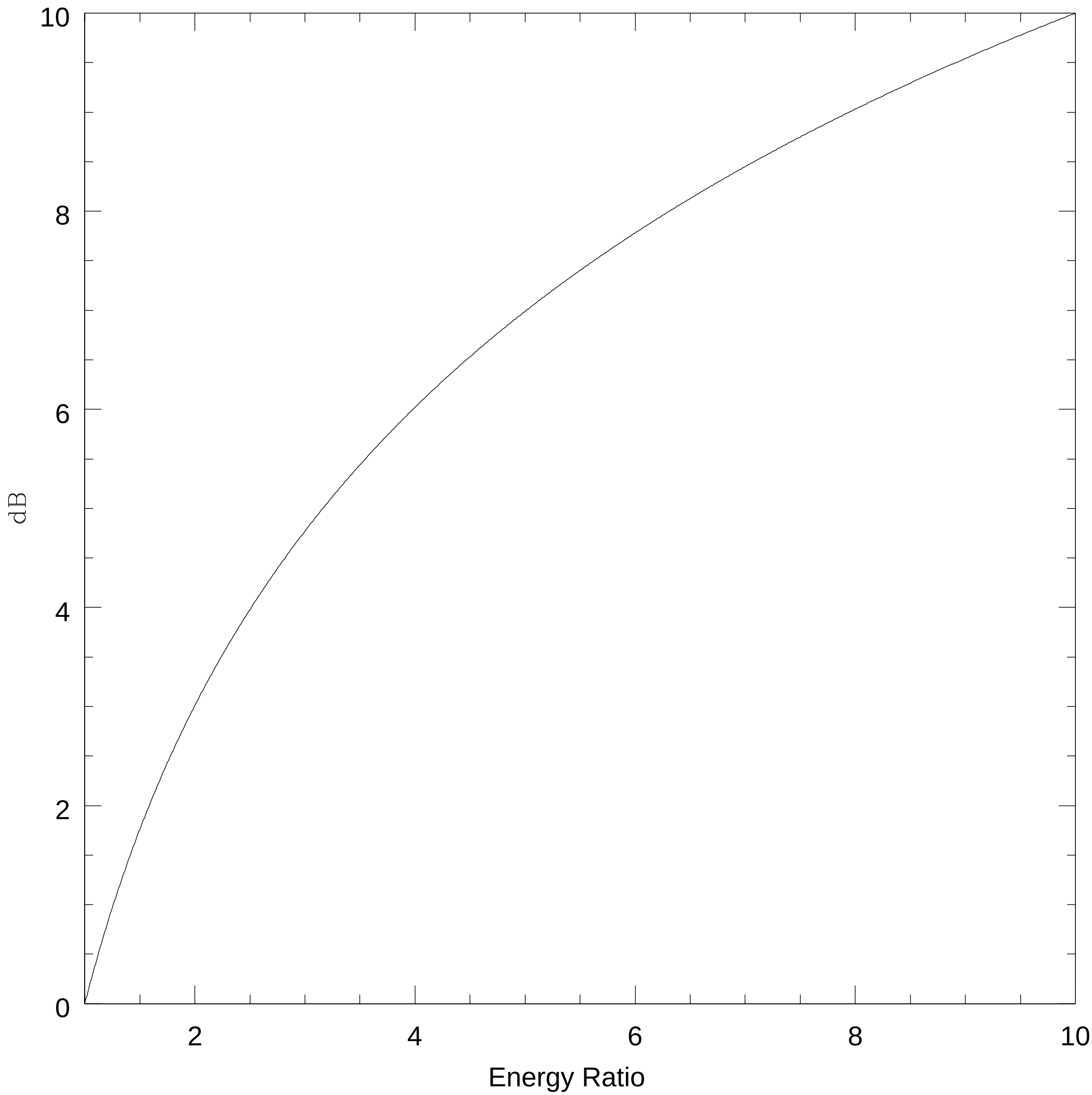
The Bel is thus a comparative scale (just as the octave is).

Just as with the octave, a Bel is too large a unit, and it is broken down into 10 subunits called deci-Bels, just as an octave is broken down into subunits called semitones and tones. There are 10 dB in a Bel, and thus the intensity ratio represented by one dB is such that that number multiplied by itself 10 times gives a factor of 10 (the Bel). This corresponds to 1.26 times as loud. Ie, each increase in loudness of 1dB correspoinds to and increase in intensity of 1.26 times.

Unlike a semitone, which is an easily distinguished change of pitch for most people, and in fact a trained musician can distinguish changes in pitch of 1/100 of that, 1 dB is roughly the limits of distinguishability of loudness for people. Ie, differences in sound intensity of less than 1 dB (of less than about 25% change in intensity) are difficult for most people to distinguish.

It turs out that 3dB correspods very closely to a change in intensity of a factor of 2 (to better than 1/10 of a perent) and this can be very handy in determining the relation between changes in intensity and changes in dB. Ie, it implies that 6dB (=3+3dB) corresponds to a factor of 4 (=2x2) in intensity, 9dB to a factor of 8, 7dB= 10dB-3dB corresponds to a factor of 5 (10/2).

However the following figure shows the relation between dB and intensity for any dB between 0 and 10.

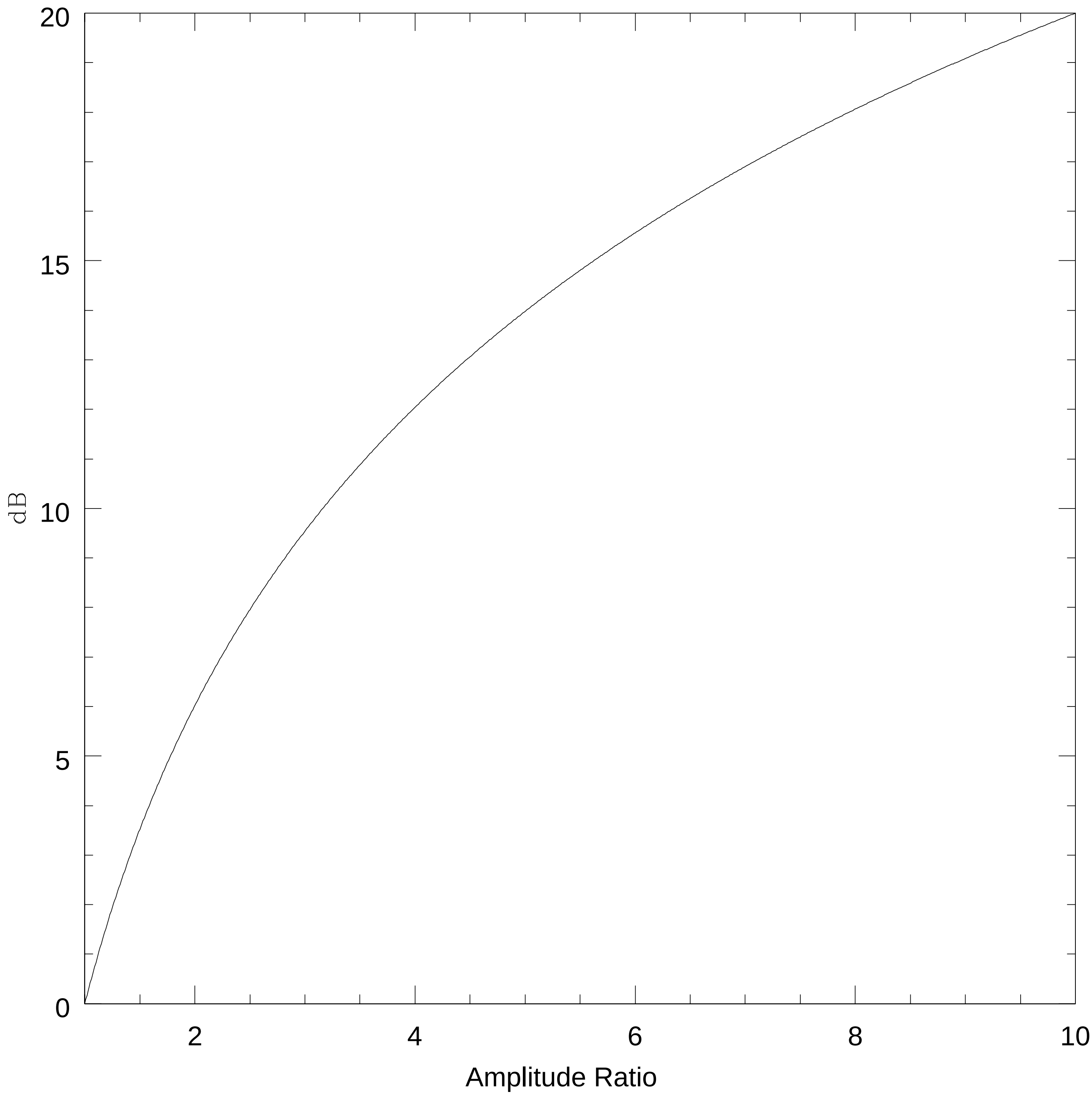


While dB is a comparative scale, (ie, it indicates a comparison in intensity between two sounds) it is also often used in an "absolute" sense, by comparing the loudness to a standard. That standard is taken to a nominal "quietest intensity that can be perceived by human hearing". Since of course human hearing varies a lot, and some people can hear quieter sounds than others, it is based on a nominal lowest intensity that a bunch of college students were found to respond to in teh 50's. This intensity is 10^{-12} watts per meter^2. (Watts is a unit of energy delivered per unit time, and the "per meter squared" is the area over which that energy is delivered). This corresponds roughly to the light energy which a 60 watt light bulb in Calgary would deliver to someone in Vancouver (assuming the mountains, and earth's curvature did not get in the way). The ear is an astonishingly sensitive instrument.

Thus on this "absolute" scale, the intensity of the sound is compared to this least intensity. If the energy delivered is 1 watt per square meter, this would correspond to sound level of 120 dB (10 dB for each of 12 multiples of 10 it takes to get from 10^{-12} to 1). This is roughly the sound level of a jet taking off as heard for about 50 meters away, or the sound level in the Comodore Ballroom on a particularly raucous night. It is a sound level which is damaging to hearing, and which Noise regulations say should be experience by any worker for less than about 30 sec or 7 min(depending on whose regulations) in any day, the rest of the day being completely quiet.

II. INTENSITY AND AMPLITUDE

While we have discussed Amplitude of an oscillation, the amplitude is not the same as the intensity. In fact the intensity of a sound is proportional to the square of the amplitude. Thus if the amplitude goes up by a factor of 2, the intensity will increase by a factor of 4 (2x2). Thus the relation between dB and amplitude is different from that between intensity and dB. An increase in amplitude by a factor of 10 corresponds to and increase in intensity by a factor of 100, or 20 dB. In figure 2, we have the graph of the relation between Amplitude and dB



Just as for intensity, people have set up a scale of absolute loudness for the amplitude of a sound, as measured by the amplitude of the pressure fluctuations in the sound. The standard chosen, 2×10^{-5} Pascal(P), (the standard pressure of the air at sea level is approximately

10^5 P), corresponds roughly to that for intensity but not exactly. Thus you will sometimes see people refering to dB pressure or dB intensity to show which standard reference they are using. Note that this difference becomes critical when one is measuring dB in media other than air (for example under water). There the reference (10^{-12} watts per meter squared) for intensity differs by about 30dB from the $2x10^{-5}$ P reference.)

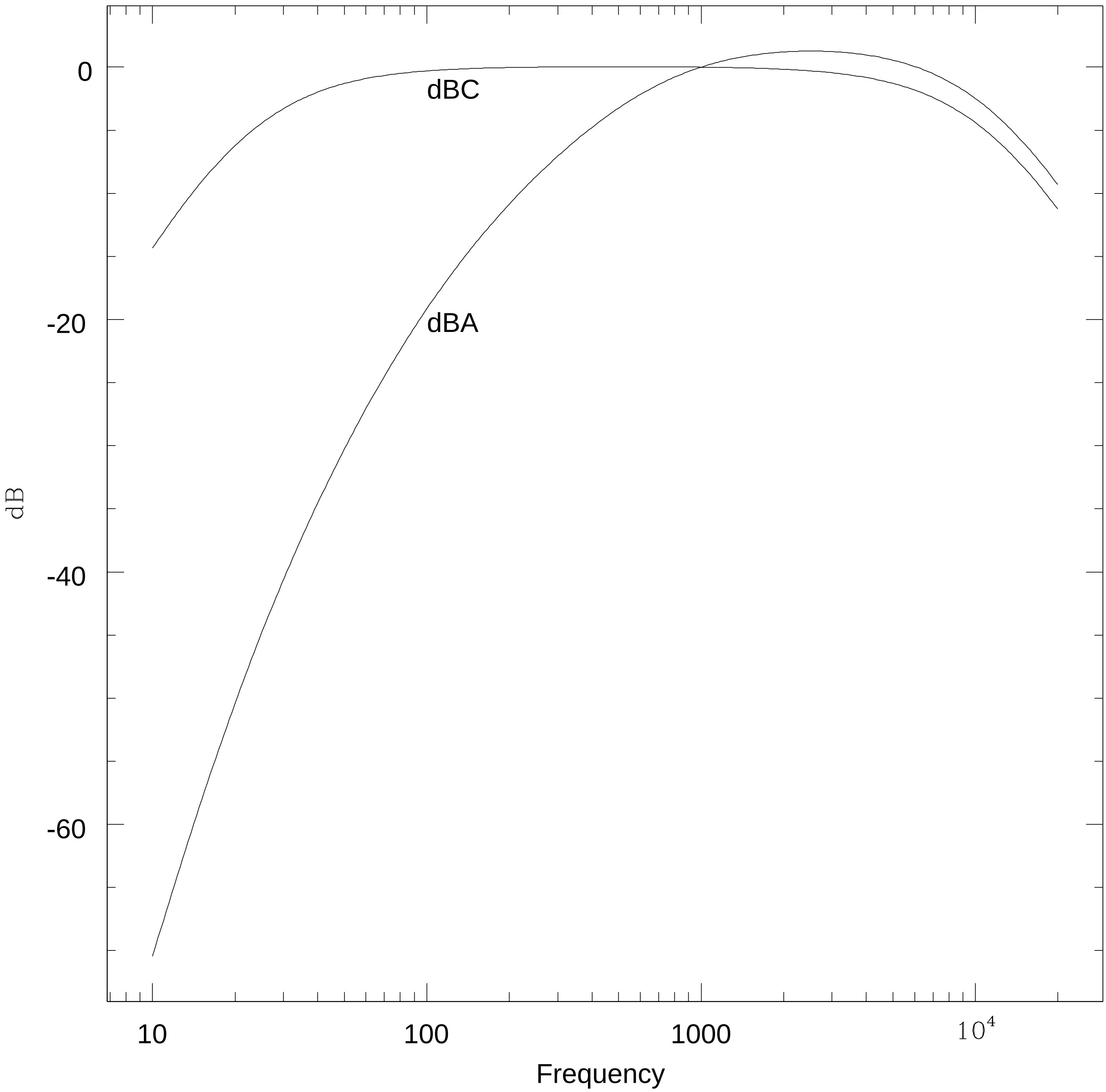
III. DBA AND DBC

Teh actual limit of human hearing of 10^{-12} Watts per meter squared (W/m^2) is defined at 1KHz (a frequency of 1000 Hz) which is close to the frequency of greatest sensitivity of the human hearing. For frequencies less than that or greater than that, the sensitivity drops off. Fletcher and Mundsen measured the hearing sensitivity of students by playing different frequencies to the students and asking them to adjust the intensity of the sound at different frequecies until it was the same as the loudness of the a given sound at 1KHz. They found that if the sound at 1KHz was 40dB, then the ear was far less sensitive especially at lower frequencies. Eg, at 100Hz the sound would have to be about 18dB more intense (58dB) to sound as lound as the sound at 40dB at 1KHz. This led to the A-weighted dB scale to approximate the perceived loudness of a sound at different frequencies. Ie, if you played two notes, one at 1KHz and one at 100Hz, the one at 100Hz would sound about 18dB quieter, or so the arguments goes.

In actual fact the experiements were fraught with difficulties, and the results have be disputed. However, almost everyone one uses this A weighted scale to measure the intensity of noise. It is almost completely inappropriate, but especially because, in setting noise standards, it allow for far higher intensity at low frequencies, it has been universally adopted for noise standards.

There is another standard the C-weighting standard which was based on the FM measurements for comparisons of loudness to a loudness of 100dB at 1KHz. In the C weighting there is little evidence of any change in preceived loudness to intensity across the audible frequency band. Since it is based on the sensitivity of the ear to loud sounds it would be be sensible if it were the one used to to set the standard for lound sounds. But sensible and legal requirements need not have any relation to each other.

In the following figure is the comparison of the A-weighted and the C-weighted scales. Ie, if we assume that we have exactly the same intensity sound (the same energy delived to the ear) at all frequencies. these scales show how much should be subtracted from the real dB rating to get the A and C weighed results.


0
-20
-40
-60
dB
dBC
dBA
10
100
1000
10^4
Frequency