DECIBELS

of Light and Sound

By ***S. S. Stevens***

THE usefulness of logarithms in the measurement of many of the stimuli to which human beings are sensitive is almost too obvious to need argument. Three reasons are commonly given to justify the practice:

1. The intensity ranges of the physical stimuli are enormous—energy ranges of trillions to one are involved in vision and hearing.
2. To a rough approximation, discrimination follows a law of relativity: the just detectable increment in a stimulus is proportional to the magnitude of the stimulus (Weber's law). Hence, to the extent that Weber's law holds, the logarithmic difference that is just detectable is constant.
3. According to Fechner's law, the subjective magnitude of a sensation is supposed to be proportional to the logarithm of the magnitude of the stimulus.

This third reason involves one of those enduring misconceptions that no amount of mere measurement seems able to dispel. Fechner's logarithmic law is attractively simple, but decidedly wrong. The fact is that the sensations of both loudness and brightness are proportional, not to the logarithm, but roughly to the cube root of the energy of their respective stimuli.[1] Nevertheless, the first two reasons are cogent enough, and we may reasonably assume that logarithmic measures of stimuli are here to stay.

In psychophysics we are frequently concerned with relative magnitudes, and there are many problems in which the ratio between the magnitudes of two stimuli is of more interest than the absolute values themselves. Here we find logarithms a great convenience, for when ratios are to be combined we can add logarithms instead of multiplying fractions.

These advantages of logarithmic measures are so compelling that most writers in the fields of vision and hearing use them as a matter of course. There is a difference, however. Those who work with sound have gone one step further and have adopted the decibel as their standard logarithmic measure. Most of those who work with light have failed thus far to see the merit of the decibel and have contented themselves with "log units", where the logarithms may refer to any of the confusing array of photometric units now in use. To some of us who work with both light and sound, this practice seems to be an unnecessary handicap. We feel that the proven utility of the decibel is too impressive to be ignored and that the benefits of the decibel notation are as applicable to light as they are to sound. Furthermore, as we shall see, certain interesting parallels between vision and hearing are made more readily apparent when decibel measures are applied to the respective stimuli.

The Origin of the Decibel

CONTRARY to popular belief, the decibel is not a unit of loudness. As a matter of fact, it did not even originate in acoustics. It was the invention of the transmission engineer whose problem was to measure the loss in power when electric signals are dispatched over transmission lines.

Like most good ideas, the concept of the decibel seems simple and obvious—*after* it has been invented. But before they hit upon it, the engineers struggled along with a measure that was about as good—or as bad—as the length of the king's right arm. They used what they called the "mile of standard cable", and they measured the power losses in an unknown circuit by comparing it to a known circuit into which "miles of standard cable" were inserted until the two circuits performed alike. But, among other inconveniences, the standard cable did not behave the same for signals of different frequency. It was variable, like the king's right arm. So in 1923 a new unit was invented, called the "transmission unit", abbreviated TU.[2] By definition, two amounts of power differ by one TU when they are in the ratio of $10^{0.1}$, and they differ by n TU when they are in the ratio of $10^{0.1n}$. The TU is approximately equal to a mile of standard cable.

In 1924 an international committee considered this

[1] S. S. Stevens, The measurement of loudness, J. Acoust. Soc. Am. (in press).
R. M. Hanes, The construction of subjective brightness scales from fractionation data: a validation, J. Exp. Psychol. 39, 719–728 (1949).

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[2] W. H. Martin, The transmission unit and telephone transmission reference systems, Amer. Inst. Elect. Engr. Trans. 43, 797–801 (1924); and Bell Syst. Tech. J. 3, 400–408 (1924).

and related matters. As a result of these deliberations there was created a new unit, the bel (in honor of Alexander Graham Bell), and the TU was renamed the decibel—a tenth of a bel.[3] This decision stuck and soon almost everyone concerned with electrical engineering was talking decibels.

The use of decibels spread quickly to acoustics. There appear to be two reasons for this. Since acoustics had no firmly established system of units and conventions there were few age-old prejudices to overcome. In addition, the most active center of research in hearing and acoustics was at the Bell Telephone Laboratories, and that is where the TU was born. When the Bell System adopted the decibel, the workers in acoustics went along with the new unit.

For a short period of time measurements of sound intensity were expressed by some authors in what were called "sensation units" (SU). This unit was equivalent to a decibel, but it seems to have gotten its name from the mistaken notion that equal steps on a logarithmic scale of acoustic intensity sound like equal steps in loudness (Fechner's law again). This notion was widely popularized and did much mischief. Fortunately the SU has dropped out of use, and everyone who has taken the trouble to listen knows that equal logarithmic steps (decibels) of sound intensity do not appear to be equal increments in loudness. The jump from 10 db to 20 db above threshold is psychologically vastly smaller than the jump from, say, 110 db to 120 db.

Actually, from one point of view, the use of decibels has much less to recommend it in acoustics than in optics. The decibel stands for a ratio between two amounts of power, whereas in most acoustical studies the quantity we most often measure is sound pressure. When acoustic power is proportional to the square of the sound pressure, a given ratio of sound pressures corresponds to twice as many decibels as does the same ratio of powers. Thus we need two formulas in acoustics: the number of decibels, N, is given by

$$N = 10 \log \frac{E_1}{E_0} = 20 \log \frac{p_1}{p_0}$$

where E is the acoustic power (energy flow) and p is sound pressure. The subscript zero indicates a reference level. Furthermore, the designation of pressure ratios by decibels is strictly proper only when p_1 and p_0 are the square roots of the corresponding values of power. Similar difficulties arise, of course, in the use of decibels for electrical measurements, where power is usually proportional to the square of the voltage, but not always.

In optics, on the other hand, we are not embarrassed by these practical difficulties in the use of decibels, because in dealing with light intensity we do not have to contend with two measures that are not linearly related. In practice, our only measure of light intensity is a power measure, either relative as in photometry or absolute as in radiometry, and consequently we need only one formula for the decibel.

[3] W. H. Martin, Decibel—the name for the transmission unit, Bell Syst. Tech. J. **8**, 1–2 (1929).

Other Uses for Decibels?

DESPITE the occasional confusion caused by the use of decibels to express ratios of quantities not linearly related to power, the decibel notation has become part of the working vocabulary of almost everyone who deals with electricity and sound. So complete is the success that some are starting to worry about the possibility that the notion has been oversold. Apparently there is a wide demand in many fields for a convenient measure of relative magnitude, and since the decibel is such a measure, we find it being used for many quantities that may have nothing to do with power. Decibels have been used to express such magnitudes as frequency band-width,[4] statistical variance, photographic contrast, etc. These and other usages attest the convenience of a logarithmic measure of relative magnitude and the borrowing of the decibel for these purposes has perhaps been inevitable.

Nevertheless, those who feel that it is important to keep the decibel tied to measures involving power have raised a protest against the indiscriminate borrowing of the decibel. Some of the objectors have recognized the insistent need for a measure of relative magnitude and have proposed various solutions, most of which involve the basic concept of the decibel under another name [5].

The problem is to devise a kind of universal decibel—a standard relative magnitude—that can be used to state the relation between the magnitudes of any two like quantities: lengths, volumes, frequencies, densities, or what you will. Horton proposed that this quantity be called a "logit" and that it be defined as "the change in relative magnitude for which the ratio of the final to the initial absolute magnitudes is $10^{0.1}$". This suggestion was approved by Hall, who appended to his discussion the thought that the term "decilog" might be a better name than logit. Green put in a strong boost for decilog, a term that was used, incidentally, by the psychologist Morgan [6] as early as 1944.

The argument for creating a new name for the ratio of $10^{0.1}$ rests on the assumption that only thereby will it be possible to reserve the term "decibel" for its original intended use, namely, to quantify the ratio between powers. This is probably a sufficient reason, and careful thought should be given to the problem of an appropri-

[4] H. Fletcher, *Speech and Hearing in Communication* (Van Nostrand, New York, 1953), p. 172.

[5] A partial catalogue of the names thus far suggested for the standard logarithmic measure includes decilog, decilu, decilit, decibrigg, decomlog, logit, and decade. See, for example, the following articles:
J. W. Horton, Fundamental considerations regarding the use of relative magnitudes, Proc. Inst. Radio Engr. **40**, 440–444 (1952);
J. W. Horton, The bewildering decibel, Elect. Engng. **73**, 550–555 (1954);
W. M. Hall, Logarithmic measure and the decibel, J. Acoust. Soc. Amer. **26**, 449–450 (1954);
E. I. Green, The decilog: a unit for logarithmic measurement, Elect. Engng. **73**, 597–599 (1954);
V. V. L. Rao and S. Lakshiminarayanan, The decilit: a new name for the logarithmic unit of relative magnitudes, J. Acoust. Soc. Amer. **27**, 376–378 (1955); and
R. V. L. Hartley, New system of logarithmic units, J. Acoust. Soc. Amer. **27**, 174–176 (1955).

[6] C. T. Morgan, The statistical treatment of hoarding data, J. Comp. Psychol. **38**, 247–256 (1945).

TABLE 1. A Classification of Scales of Measurement

The basic operations needed to create a given scale are all those listed in the second column, down to and including the operation listed opposite the scale. The third column gives the mathematical transformations that leave the scale form invariant. Any numeral x on a scale can be replaced by another numeral x' where x' is the function of x listed in column 3. The fourth column lists, cumulatively downward, examples of statistics that show invariance under the transformations of column 3.

Scale	*Basic Empirical Operations*	*Mathematical Group-Structure*	*Permissible Statistics (invariantive)*	*Typical Examples*
NOMINAL	Determination of equality	Permutation group $x' = f(x)$ where $f(x)$ means any one-to-one substitution	Number of cases "Information" measures Contingency correlation	"Numbering" of football players Assignment of type or model numbers to classes
ORDINAL	Determination of greater or less	Isotonic group $x' = f(x)$ where $f(x)$ means any increasing monotonic function	Median Percentiles	Hardness of minerals Grades of leather, lumber, wool, etc. Intelligence test scores
INTERVAL	Determination of the equality of intervals or differences	General linear group $x' = ax + b$	Mean Standard deviation Product moment correlation	Temperature (Fahrenheit and Celsius) Position Time (calendar) Energy
RATIO	Determination of the equality of ratios	Similarity group $x' = ax$	Geometric mean Harmonic mean Coefficient of variation Logarithms, decibels	Length, weight, density, resistance, etc. Temperature (Kelvin) Time intervals Energy differences (work)

ate name and an appropriate abbreviation for a general measure of relative magnitude. The term decilog has much to recommend it because it suggests an analogy with decibel, and it is reasonably self-explanatory. It clearly suggests that it is a tenth of a logarithmic unit.

The number of decilogs would be given by

$$N = 10 \log \frac{A_1}{A_0}$$

where A refers to any quantity measured on a *ratio scale*.

Abbreviations previously suggested include "DLU" (for decilog unit) and "dg". The letters "dl" would be more analogous to "db" of the decibel system, but "l" is ambiguous on the typewriter and in psychophysics the just detectable increment in a stimulus is known as a "difference limen" and is abbreviated "DL". Thus we would face the potential confusion of having to measure DL's in dl's! Perhaps the best choice would be decilog for the name and "dg" for the abbreviation.

The restriction of decilogs to quantities measured on ratio scales is an obvious necessity when we consider the nature of measurement and the four classes of scales of measurement.[7] The four kinds of scales are shown in Table 1, together with the basic empirical operations on which each type is based and the resulting mathematical group structure of the scale. It is only on what I have called the ratio scale that ratios stay put under the transformations allowed by the scale (multiplication by a constant). All other scales permit more general kinds of transformations. Even the interval scale permits a general linear transformation, involving the addition of a constant, and on these scales the ratio between two values has no meaning because it can be altered at will—as, for example, when we convert from Fahrenheit to Celsius. The use of decilogs would be out of bounds for all scales other than ratio scales.

[7] S. S. Stevens, On the theory of scales of measurement, Science **103**, 677–680 (1946). See also Chap. 1 of S. S. Stevens (ed.), *Handbook of Experimental Psychology* (Wiley, New York, 1951).

As is true for decibels, two additional cautions should be observed. The author who uses decilogs should make it plain what quantities are being compared. As Horton says, "The nature of the physical quantity in question is as pertinent to operations with relative magnitudes as to those with absolute magnitudes." And when he uses decilogs to express the absolute magnitude of a quantity, the author should be careful to state the reference level of his decilog scale (the value of A_0 in the equation above). For example, the statement that the intensity of a sound is 60 db has no meaning unless we know what value corresponds to zero db. The same would be true of decilogs.

Photometry

IT would be possible, of course, to measure light intensity in decilogs. But since light intensity involves power (radiant energy flow) it is equally appropriate to measure light in decibels. Why is this not done more widely? (In the *Handbook of Experimental Psychology*,[8] some use of decibel scales was made at my suggestion by D. E. Judd and S. H. Bartley, but I know of no other published instance.[9]) The problem seems to be

[8] S. S. Stevens (ed.), *Handbook of Experimental Psychology* (Wiley, New York, 1951).

[9] Mention should be made, however, of an unpublished report: Notes on Photometry, Colorimetry, and an Explanation of the Centibel Scale, by Wayne B. Nottingham, Radiation Laboratory (MIT) Report 804, 17 December 1945. In order to simplify its work on the luminescent properties of cathode-ray tubes, the wartime group at the Radiation Laboratory devised a logarithmic measure of relative magnitude which they called a "centibel" and abbreviated "cb." This measure, equal to a tenth of a decibel, serves all the useful functions of the decibel. A possible argument for using this smaller standard of relative magnitude in visual studies is that the eye is sensitive to smaller differences than is the ear. Under favorable conditions, the visible DL is of the order of a centibel. In any case, going from centibels to decibels and vice versa is as easy as changing millimeters to centimeters.

Another reason for the use of centibels rather than decibels seems to have been the approximate proportionality in a photocell between radiant *power* input and *voltage* output. Thus a 3-db increase in light input doubles the voltage output, but the doubling of a voltage conventionally means a change of 6 db. I am informed by Pierre Mertz of the Bell Telephone Laboratories that he was concerned with this source of potential confusion when he proposed a decibel scale for measuring light in 1937.

mainly one of inertia. Photometry is vastly older than electrical or acoustical engineering. Its antiquity is shown by the fact that as early as 1613 the master Rubens drew illustrations for Aguillon's book on optics in which he pictures a photometer in all its essentials—complete with cherubs as operators.[10] This was more than a century before the "invention" of the photometer by Bouguer. As we might expect in so old a discipline, the conventions that dominate the field were well crystallized long before the decibel was invented. Coupled to this fact is the widespread misconception that the decibel is a unit of loudness.

Perhaps the decibel would have more appeal in the science of vision if it paraded under a name that honored, not the inventor of the telephone, but the author of the field's great classic: *Handbuch der physiologischen Optik*. We could abbreviate Helmholtz to "helm" and call our measure the "decihelm," abbreviated "dh," and defined as we define the decibel. This suggestion was made by my colleague, J. G. Beebe-Center. Since then I have heard other interesting suggestions. L. M. Hurvich offers decilam, to honor Lambert, and D. B. Fry suggests that we might drop the m from decihelm and thereby simply honor helios, the sun. The use of any such term would have the advantage that we would always know that it referred to light and not to electricity or sound. The disadvantage is that it would multiply terminology, and it would be a minor inconvenience for those of us who like to plot intensities of light and sound against a common scale for the purpose of comparing psychological effects.

Whatever we call it, a convenient logarithmic measure of relative magnitude has many advantages for those who work with light and vision.

1. It simplifies many calculations. John Napier wrote to his "right well beloved students of mathematics" that he invented logarithms in order to simplify calculations, and in this he certainly succeeded. Logarithms are, of course, widely used in optics, but not so extensively as decibels are used in acoustics. It is true that optical density is commonly given as the logarithm of the ratio between the incident and the transmitted light. Thus a neutral filter of density 1.0 is analogous to a 10-db electrical attenuator, and, as with electrical attenuators, the total transmission loss due to a series of neutral filters is the sum of the individual losses. In other words the numbers used to designate optical densities behave like bels. Since the decibel is a more convenient size than a bel, it would be an obvious convenience if we could rate the density of neutral filters in decibels—and then extend the procedure to all light ratios instead of those dealing only with the attenuation of light by emulsions.

2. The decibel notation saves space. It is shorter, for example, to say that two lighted surfaces differ by 3 db than to say that they differ by 0.3 logarithmic unit, or that they differ by a ratio of two to one.

3. When visual problems concern, as they often do, only the relative magnitudes of stimuli, a measure like the decibel is the natural unit to use. With decibels we state the ratio between two luminances without involving ourselves with millilamberts, stilbs, blondels, foot-lamberts, nits, or any of the other linearly related measures of luminance.

4. For the designation of absolute quantities we merely choose a convenient reference value and express other quantities in terms of decibels above or below that quantity. Different references are used for different purposes, but it is convenient to standardize certain reference levels. In particular, it is desirable to standardize a reference level for luminance (photometric brightness) such that all visible luminances are expressed by positive values on the decibel scale.

In my own work on brightness I have used a reference level set at 10^{-10} lambert. Like the analogous reference for sound measurements (10^{-10} microwatt per cm^2) this reference is slightly below the normal absolute threshold for the most sensitive region of the dark-adapted eye. Hence the decibel levels of all visible luminances are positive. In stating the reference level in the lambert system I am making a concession to the fact that the most widely used unit in this country seems to be the millilambert. If it were necessary to change to some other reference I would merely add or subtract an appropriate number of decibels. Stated in the mks system, the proposed reference level is $1/\pi \times 10^{-6}$ candles per square meter.

A potential windfall that might follow from this simple procedure is the standardization of photometric units. Chapanis[11] calls this "one of the most pressing problems confronting visual scientists at the present time". I realize that many scholars have set boldly out to force order into the chaos that exists among the photometric units, and that they have often succeeded only in adding to the lists of alternative names and units. In the decibel system, however, we have the possibility of solving the standardization problem by the simple expedient of avoiding it. At least we can avoid arguments about units by fixing a reference level and using decibels. Of course, we might argue about reference levels, but since this is a new subject the problem of pride, individual and national, is not yet involved, and maybe we can reach agreement before anyone begins to claim a vested interest. Even if we cannot agree, it is such a simple matter to change from one reference level to another by adding a few decibels that no one need be greatly inconvenienced. It is not like converting, for example, from millilamberts to stilbs via a multiplication factor of 3.183×10^{-4}.

Armed with a decibel scale based on a convenient reference like 10^{-10} lambert, we can tabulate, as in Table 2, the decibel levels of the various units of luminance that we are apt to encounter. We also see in this process what a confusion of units there is.[12] With

[10] E. C. Watson, Reproduction of prints, drawings and paintings of interest in the history of physics: 37, Rubens as a scientific illustrator, Amer. J. Phys. **16**, 183–184 (1948).

[11] A. Chapanis, How we see. In *Human Factors in Undersea Warfare* (National Research Council, Washington, 1949).

[12] For a thorough table of conversion factors, see P. Moon and D. E. Spencer, Utilizing the mks system, Amer. J. Phys. **16**, 25–38 (1948).

the aid of Table 2 I have found it a simple matter to place on a single decibel scale the values reported in various units by different authors writing on the same topic.

TABLE 2

Unit of luminance	*Level in decibels re 10^{-10} lambert*
Candle per square millimeter	124.97
Candle per square centimeter (stilb)	104.97
Lambert	100
Candle per square inch	96.88
Candle per square foot	75.29
Foot-lambert (equivalent foot-candle)	70.32
Millilambert	70
Candle per square meter (nit)	64.97
Blondel (apostilb)	60
Microlambert	40
Millimicrolambert	10
10^{-10} Lambert	
$1/ \times 10^{-10}$ Stilb π	0
9.29×10^{-8} Foot-lambert	

A similar table can be made for the various units of illuminance (illumination). In Table 3 we have set the reference level at 10^{-10} phot or 1 kilometer-candle. We then obtain for the common units of illuminance the various decibel levels shown.

TABLE 3

Unit of illuminance	*Level in decibels re 10^{-10} phot*
Phot (centimeter candle)	100
Foot-candle	70.32
Milliphot	70
Lux (meter-candle)	60
10^{-10} Phot	
Kilometer-candle	0
9.29×10^{-8} Foot-candle	

The reference levels in Tables 2 and 3 are so chosen that an illuminance of 100 db falling on a perfectly reflecting and diffusing surface produces a luminance of 100 db.

These photometric measures, luminance and illuminance, are the two most commonly used in the visual sciences. Like all photometric concepts, they go back for their meaning to the "standard candle", which in the old days was indeed an actual sperm candle of standard size. Now we have a more accurate standard: a "black body" at the temperature of the freezing point of platinum has a luminance of 60 candles/cm². The science of photometry proceeds on the assumption that we can use the human eye as a null instrument to equate a luminance derived from the standard source to an unknown luminance, and thereby measure the unknown luminance. This use of the eye as a null instrument raises a host of nasty problems, which we need not worry about here. Suffice it to say that the decibel scales in Tables 2 and 3 are based on the assumption that, regardless of the properties of the eye, when we reduce the output of a standard source by a ratio of 10 (keeping the spectrum constant) we effect a light reduction of 10 db.

In some ways it is unfortunate that the optical sciences were not able at the outset to use absolute radiometric measures and thereby avoid the pitfalls of photometry. Perhaps because the development of acoustics was so slow in coming, the acoustical sciences have never become saddled with an elaborate "phonometry" in which some arbitrary source of sound was taken as a standard in terms of which all other sounds were rated. Instead, acoustics has developed around measures that are analogous to radiometric measures in optics—measures like watts rather than lumens. Some scientists, particularly those who study the responses of animal eyes, have urged that for scientific purposes we should give up photometry and describe visual stimuli only in radiometric terms. This is a sound notion,[13] entailing however some practical difficulties. But regardless of whether we use radiometric or photometric scales, the decibel notation is both applicable and helpful.

Comparison between Vision and Audition

HAVING chosen appropriate reference levels we can illustrate one of the utilities of decibels by arranging a common decibel scale for sound intensity and for light intensity (luminance) in such a way that interesting similarities between vision and hearing are at once apparent. This decibel scale is shown in Fig. 1. On either side of the scale are shown various representative levels of light and sound.

First we note that the brightness level of the sun, our major source of illumination, is about the same number of decibels above threshold as is the noise measured a few feet from a jet plane, which is probably the loudest sustained man-made noise. Listening to such a noise is hard on the ears, just as looking at the sun is hard on the eyes. Both are far above the level at which discomfort begins, which is in the vicinity of 120 db for both senses. The comfortable brightness for seeing and the comfortable loudness for listening are both near the middle of the decibel scale, and when stimuli are less than about 40 db we strain to perceive them. Below about 35 db we see only with the rods of the eye (scotopic vision); above this level the cones come into action (photopic vision).

It is clear from Fig. 1 that both vision and hearing cover an enormous dynamic range. In terms of stimulus power, the ranges are roughly similar in the two senses —so similar in fact that I have been led to enquire whether the two sensations follow the same path as a function of stimulus intensity. Do subjective brightness and subjective loudness grow according to the same law? The answer seems to be that to a fair approximation they do. When an observer is asked to choose a luminance (white light) that looks to him half as bright as a moderately bright standard stimulus, he chooses one about 9 db less than the standard. When he is asked to choose a level of white noise that sounds half as loud as a standard noise, he does about the same thing.

In an experiment being conducted by Joseph Stevens,

[13] See P. Moon, *The Scientific Basis of Illuminating Engineering* (McGraw-Hill, New York, 1936), p. 545.

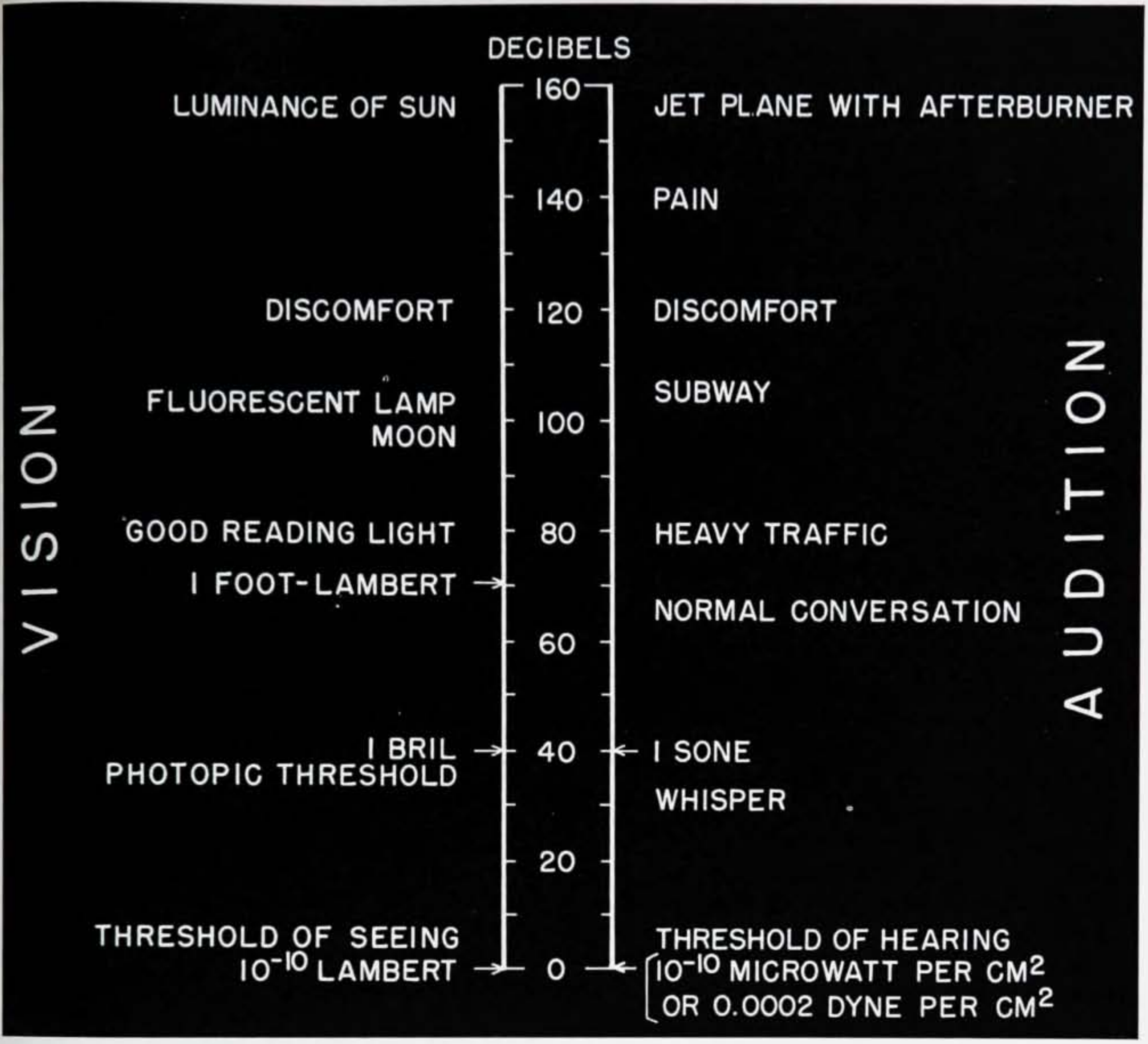

Fig. 1. A decibel scale for light and sound, showing the approximate levels of luminance and of sound intensity produced by various sources, together with a few important threshold levels. The points indicated by arrows are exact levels fixed by definition. The other levels are approximate only.

we have presented pairs of different luminances and have asked observers to adjust pairs of noises to make their loudnesses appear to be subjectively in the same ratio as the brightnesses. On the average the subjects set the same decibel difference between the noises as the experimenter sets between the luminances.

These facts suggest that a subjective scale can be constructed for brightness, as indeed Hanes has already shown, and that the brightness scale will resemble the so-called sone scale already constructed for loudness. Since I have defined the sone (the subjective unit of loudness) as the loudness heard when a 1000-cycle stimulus is at a level of 40 db, it seems appropriate to suggest that the bril (the subjective unit of brightness) be set at a comparable level. This proposal is indicated in Fig. 1. The bril, then, is the brightness seen by the normal dark-adapted eye when the luminance of the target is 40 db above the (tentative) standard reference level. As we see in Table 1, this level of 40 db is equivalent to 1 microlambert. The subjective unit proposed by Wright,[14] which he called a "brill", was set at 34.45 db on our scale.

These similarities between vision and hearing are easy to exhibit on decibel scales. They would be rather obscure otherwise. Not only is the decibel a computational convenience, but its use in psychophysics makes it easier to describe similarities and differences between the senses. The universal employment of decibel scales will undoubtedly lead to a rewarding cross-fertilization between the sciences of vision and hearing.

[14] W. D. Wright, *Researches on Normal and Defective Colour Vision* (Mosby, St. Louis, 1947), p. 285.