Noise and the Nation*

By Dr. G. W. C. Kaye, O.B.E.

SIMULTANEOUSLY with the remarkable growth of applied acoustics, there has gradually developed in Great Britain a public consciousness of the insidious growth of the social evil of needless noise—a pernicious by-product attributable in great part to an increasingly mechanized civilization. With this growing realization, the nation is beginning to demand and to receive protection against the nuisance of outrageous noise whether generated by private or public bodies. It is looking for ways and means of mitigating excessive transport noises, particularly on the road and in the air, and it is seeking to know why in modern houses or flats it should not be accorded adequate privacy against the natural, though sometimes unreasonable, noises of neighbours.

THE MEASUREMENT OF NOISE

It is common knowledge that most noises are complex in character, containing a variety of components which may be distributed over the entire auditory ranges of frequency and intensity. Such a physical constitution lends itself to objective measurement and analysis, but apart from the psychological aspects, there are subjective factors of prime importance to the listener, namely, pitch, timbre and loudness, and these sensations are not readily appraisable. Experience indicates, however, that while the composition of a noise is not to be ignored, sheer loudness is the determining factor in most cases of annoyance caused by noise, so that the problem largely resolves itself into the correlation of the sensation of noisiness (as assessed by the ear) with the associated energy, which can be quantitatively measured by physical instruments.

Let us first consider the measurement of acoustical energy. For the purpose, we need an intensity meter, this commonly consisting of a microphone and amplifier together with a suitable rectifier and indicator. Moving-coil or ribbon microphones are sometimes employed, though for fundamental work the condenser or the crystal microphone is preferred despite the lower sensitivity. Whatever the microphone used, it is usually calibrated by direct interchange comparison under appropriate

conditions with a standard (pressure) microphone of the condenser type, which in turn has been fundamentally calibrated in absolute units by means of either the Rayleigh disk or the piston-phone.

The Rayleigh disk depends for its operation on the tendency of a small thin glass disk suspended from its edge by a fine fibre to set itself at right angles to a sound field. The torsional constants of the system and the degree of deflection of the disk afford the sound particle velocity, the corresponding sound pressure being calculable from the known relations in the field. The measurements are made either in a stationary-wave pipe or in a room with highly absorbent walls.

The piston-phone, which measures sound pressures directly, consists essentially of a small cavity, one face of which is closed by the diaphragm of the standard microphone, the opposite face consisting of a small piston connected to the moving coil of a loudspeaker unit. The amplitude of motion of the piston, when it is set in vibration, is measured optically and enables the corresponding sound pressures in the cavity to be calculated.

So much for intensity measurements. As regards the associated loudness levels, we turn to auditory diagrams of the ear, such as those of Fletcher and Munson. The various loudness contours for pure tones of different frequencies show that while loudness and energy are manifestly related, the two do not normally keep in step, particularly for notes of very high and very low frequencies. At feeble intensities, the ear exercises pronounced selective preference for notes of medium frequency, and it is only at high intensities that equal increments of energy produce even approximately equal increments of loudness. Furthermore, the thresholds of hearing are much higher for high and low frequencies, so that the corresponding ranges of intensity with which the ear can deal are more restricted than for notes of medium frequency. The situation is worsened in the case of complex sounds or noises since the loudness is affected by their character, there being in general no simple relation between the loudness of a noise and the energy-loudness characteristics of its several components. It is evident that an energy meter, such as a microphone system, cannot unreservedly be used as a direct measurer of loudness.

* From the presidential address to Section A (Mathematical and Physical Sciences) of the British Association, delivered at Nottingham on September 2.

THE DECIBEL AND THE PHON

The next step in the measurement of noise is to equip ourselves with units and standards of loudness. In this connexion, we have to cater for the enormous intensity range of the ear, particularly for notes of medium frequency, where the greatest intensity that can be tolerated (the threshold of pain) is some 10 million million (10^{13}) times that corresponding to the threshold of hearing. In such circumstances, we turn, as always, to a geometrical rather than an arithmetical scale, and the unit adopted for the purpose is the *bel*, which is a ratio signifying a 10-fold increase in intensity, power or energy. Two bels signify a 100-fold increase, three bels a 1000-fold increase, and so on.

Equipped with such seven-league boots, and starting at a zero approximating to the threshold of hearing, we can traverse the entire auditory intensity range for a medium-frequency note in as few as thirteen geometrically progressive steps. But the steps are too big for practical convenience and so it is usual to speak of a range of 130 *decibels*, which provides a serviceable energy scale. Arithmetically, a decibel (db.) denotes approximately a $5/4$ energy increase (that is, antilog $1/10$), two decibels a $(5/4)^2$ increase, three decibels a $(5/4)^3 = a$ 2-fold increase, . . . 10 decibels a $(5/4)^{10} = a$ 10-fold increase, that is, a bel. More generally, two similar sounds of intensities I and I_0 and corresponding acoustical pressures p and p_0 are said to differ in intensity by n decibels when

$$n = 10 \log_{10} (I/I_0) \\ \text{or } n = 20 \log_{10} (p/p_0)$$

If I_0 or p_0 corresponds to some selected zero, then n becomes the number of decibels above that zero level.

Thus provided with an acoustical intensity scale, we can proceed to set up a loudness scale which is based on the accepted ability of the average individual to compare and match loudness. To this end (just as in photometry we make use of a standard candle) we need a standard sound; and for the purpose a pure reference tone is chosen which, on the British Standard Scale, has a frequency of 1000 cycles per second. We also require a zero of loudness at or near the threshold of hearing, and this is arbitrarily adopted as corresponding to a pressure of 0.0002 dyne per sq. cm. If now we operate the reference tone by successively increasing decibel steps of energy, the associated changes of loudness are expressed in numerically identical steps on a scale of *phons*. That is, if the reference tone is excited by an intensity of n decibels above the zero, the loudness is n phons. The equivalent loudness of any other sound or noise is evaluated by matching it by ear

under specified conditions against the suitably adjusted reference tone, the numerical value of the latter in phons then giving the equivalent loudness of the sound to be measured. Thus by this procedure we have set up a subjective scale of equivalent loudness, the unit being the phon.

It happens that a phon corresponds roughly to the smallest difference of loudness which can be detected by alternate listening, in the case of a sound of medium frequency and moderate loudness. Experience shows, too, that for many loud noises of common occurrence the loudness level in phons is approximately equal to the intensity level in decibels—a convenient relation for many purposes.

A number of different zeros of loudness have unfortunately been employed in the past; for example, 1 millidyne per sq. cm., which results in numerical values of loudness some 14 phons less than with the British Standard zero. In Germany the phon is based on a zero of 0.0003 dyne per sq. cm., which is equivalent to a 4 db. difference from the B.S. zero. As, however, a different method of listening is employed, the slight discrepancy between the two scales is not known exactly. The American scale agrees with the British, except that in the United States it is customary to use the decibel not only for expressing intensity measurements, but also for loudness levels, it being implied in the latter case that the decibel figure quoted refers to the energy level (above the arbitrary zero) of the standard tone when it matches the sound to be measured. As already mentioned, the British Standards Institution recommends that for greater clarity the decibel should be restricted to energy ratios; and in its definition of the phon, the Institution kept open the way for eventual international agreement on the unit of equivalent loudness.

Happily such agreement came about at an international conference held in Paris last July, when it was unanimously agreed that the decibel and the phon should be adopted respectively as international units of intensity level and equivalent loudness, full agreement being secured on questions of the reference tone (1000 cycles per second), the reference zero (0.0002 dyne per sq. cm.) and the technique of listening. All these matters are in accord with the definitions in the acoustical glossary of the British Standards Institution.

NOISE METERS

Subjective noise meters.—Subjective noise meters depend on the equality matching of the loudness of a noise, as heard by the ear, with a reference tone (usually a pure tone of specified frequency and of graduated intensity) as heard in a telephone

earpiece held tightly against one ear. The reference tone may be produced by an electric buzzer, valve oscillator or other means, various frequencies (for example, 1000 or 800 cycles per sec.) or mixed tones being used in commercial instruments. The usual Barkhausen technique involves simultaneous listening to the noise and the reference tone, but experience indicates that inconsistencies which are found to arise in aural measurements under such conditions are largely resolved when the two sounds are heard alternately for periods of not less than a second. Such a technique has been

unexpected or single impulsive sounds, the aural assessment presents great difficulties to the average observer.

Objective noise meters.—The problem of the designing of objective sound and noise meters, which has received much attention both in Great Britain and abroad, is of considerable complexity. The ideal aimed at by objective meters is to be able to measure every type of sound and noise on the subjective scale of phons, that is, to simulate the selectiveness and response of the average ear in all circumstances.

Approximate loudness levels of common noises.

B.S. Loudness scale of phons.

Fig. 1.

facilitated by Churcher in a subjective meter employing two earpieces, so that either the noise or the reference tone can be heard in turn using both ears simultaneously.

Subjective meters are useful for certain purposes, but the aural judging of equality of loudness of the reference tone and of a noise very different in character is not always easy. Observers are found to differ widely in their judgments, and the same individual is not always consistent. The accuracy of appraisalment of a single observer is normally low (say 5 phons), and a team of trained observers is essential for higher precision (say 2 phons). In the case of

sounds, the inertia of the instrument has to be of the right order to give readings corresponding to average aural appraisalment.

There can be little doubt that the future of sound or noise measurement, from a practical point of view, lies with the objective meter. Even in its present state of development, its practical convenience often outweighs its limitations. It is free from personal bias, rapid in action and direct reading, and can be put into the hands of an untrained observer. Furthermore, as a dial instrument, it is well adapted to the enforcement of regulations or specifications.

The various objective meters on the market all consist essentially of a pressure microphone connected to an amplifier provided with calibrated control, followed by some type of rectifier and an output indicator. As a first essential, objective meters are constructed to give the same reading for a range of steady pure tones which sound equally loud to the ear whatever the frequency. This is achieved by introducing into the amplifier electrical networks designed to modify the shape of the frequency characteristic so that it imitates the ear sensitivity at selected loudness levels. If the network is omitted, the meter measures intensity levels. Objective meters should be further designed to simulate the salient characteristics of the ear in dealing with either steady or impulsive sounds. For example, the ear does not record full strength until a steady sound has persisted for about one-fifth of a second, and in the case of pulsating

NOISE-LEVEL MEASUREMENTS

In connexion with problems of noise abatement, the National Physical Laboratory has made measurements and analyses of many noises of very varied origin. The positions which some of these noises occupy in a scale of phons are shown in Fig. 1, the upper half of which includes various noises the abatement of which would be acceptable in many circumstances. This is illustrated by the homely test which most of us apply as a test of background of noise, namely, the ease with which conversation is possible. At 60 phons, conversation is 'comfortable'; at 90 phons, difficult; and at 110 phons, virtually impossible.

Among the noise problems on which the Laboratory has been consulted in recent years, are the mitigation of the noises associated with aeroplane cabins and engine-testing factories, trains, ships, tube railways, buses, motor horns, pneumatic drills, printing works, transformer substations, cathedrals, assembly halls, business offices, flats, miniature rifle ranges, building operations, and so on. Assistance is also being given in connection with the Home Office experiments on air-raid warnings.

The loudness of a noise depends, of course, on its remoteness and to a less degree on its environment. The inverse square law appears to be followed fairly exactly in the open for average sounds such as those of motor vehicles. In a room or a tunnel, the law does not hold and a noise sounds louder than it would outside, owing to the building up of the sound level by multiple reflection. Similar conditions prevail in a narrow busy

street and contribute to the noise discomfort of the occupants in the upper stories, though to a pedestrian the noise of, say, a passing car is but little louder than in an open space. Incidentally, drivers of cars are familiar with the sudden access of high-pitched components from the engines, exhausts or tyres of their cars as they pass reflecting walls or fencing or even minor way-side objects such as tree trunks or telegraph poles.

One has also to remember that the path of a sound may appreciably modify its composition. For example, the high-frequency components may be abnormally reflected or absorbed as compared with lower notes which tend to pass through or round obstacles. Even in the open, a hedgerow or a barrage of trees may, to a limited extent, so serve as a muffler of traffic noise. The high-pitched components of a sound may further be selectively enfeebled in passing over different types of ground, for which the sound absorption may be three or four times as much for high notes as for low. To judge by experience, the absorption figures for newly fallen snow must be rather high, though I am not aware that they have been measured. High-frequency components may also be selectively absorbed by the air itself if it is humid. Knudsen has shown that the effect is due to interaction between the oxygen and water molecules, the nitrogen playing no part. Incidentally, he estimates that if we lived in an atmosphere of oxygen at a humidity of about 20 per cent, the high notes of the violin and piccolo would be completely inaudible 50 yards away.

(To be continued.)

The Sex Ratio*

By Prof F. A. E. Crew

THE subject of the numerical proportions of the sexes in a population necessarily appeals to so many interests that it is not surprising to find that considerable attention has been paid to it. But so complicated are the problems that cluster around it that even yet our understanding of the significance of the sex ratio is still very incomplete. Recent developments in cyto-genetics have removed many of the difficulties that have surrounded this subject, so that it is possible now to re-examine the problem more hopefully.

The Registrar-General's Report for 1935 shows that the secondary sex ratio was 105:100; that

the sex ratio among those babies who died during the 7th-9th months of intra-uterine life was 110:100; that there is a remarkable swing in the sex ratio, a numerical preponderance of males amongst the earlier age groups of the population giving place to a numerical equality of the sexes amongst the 15-19 year olds, whilst amongst the 20-24 year olds the females actually begin to outnumber the males; and thereafter, as age group succeeds age group, this female numerical ascendancy progressively increases until, among the 85's and over, there are more than twice as many women as men.

This swing in the sex ratio from high to very low is shown to be the result of a sexually selective

* From the presidential address for Section D (Zoology) of the British Association, delivered at Nottingham on September 2.