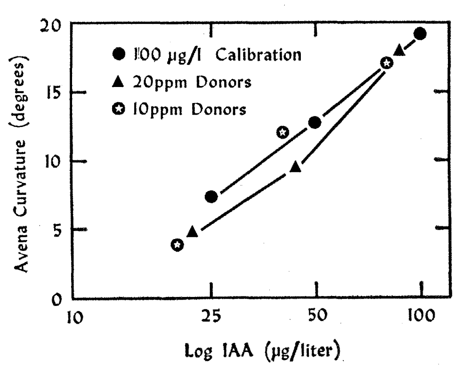

Fig. 2. Average curvatures from the *Avena* method of bioassay on undiluted, 1 : 2, and 1 : 4 dilutions of basal receiving blocks from segments treated apically with donor blocks containing 10 and 20 ppm IAA. Data from parallel dilutions of blocks containing 100 μg IAA per liter are shown as solid circles. Transport time was increased to 3 hours in order to increase the over-all yield.

donor block are not significantly different by the *t* test. Each of the six individual experiments showed a curve of the same general shape.

Since the *Avena* curvature test, which is routinely used for the bioassay of auxin, has been reported to show that higher concentration does not increase the curvature proportionately *(6)*, we must demonstrate that the receiving blocks obtained when the concentration in the donor block was 10 and 20 ppm do not contain two different concentrations of auxin both of which appear on the plateau in the bioassay (*1*).

Parallel dilution series provide such evidence (Fig. 2). The results support the view that the donors whose concentrations were 10 or 20 ppm did not cause transport into the basal receiving blocks of amounts of auxin corresponding to those on the plateau. They also support the view that the amounts in the two types of receiver are the same, about 80 μg/liter. Finally, the agreement evident in the shapes of the response curves supports the hypothesis that the material measured in the receiving blocks is predominantly IAA. Of the 10 dilutions tried, only one showed a value that was surprising. This unexpected result occurred in a 1 : 4 dilution when the value was expected to be low.

This limitation of the amount of auxin transported at the higher concentrations of the donor block is apparently not found only in *Coleus*. A close look at the data, as contrasted to the conclusions, in some earlier investigations supports this view. For instance, a similar "plateau" effect is indicated by data on the transport of IAA through pear twigs (*7*), and even Went's results on the *Avena* coleoptile provide—within the critical range when the concentration in the donor block is 1 to 10 ppm—evidence of a similar plateau (*4*). Scott and Briggs have just shown that older, nonelongating portions of the pea stem transport only the normal endogenous amount of auxin even after exogenous IAA has been applied for a time sufficient to result in an abnormally high content of extractable auxin (*8*). Recent findings indicate that a similar limitation of transport occurs in the coleoptile of *Avena* (*9*). Recovery of C^{14} in the receiver blocks from labeled IAA in the donor blocks, approaches a maximum for 7-mm sections when the concentrations of the donor blocks are 0.8 and 1.6 ppm.

This limitation of the transport of hormone is potentially important. Results to date suggest that this limitation of transport is a controlling valve which prevents excessive production of auxin from disturbing the balanced coordination of normal development (*1*). The available evidence though scanty also suggests that the concentration in the donor block at which the limitation begins to assert itself will vary with species; this variation is between 2 and 5 ppm for *Coleus* stems, 0.8 and 1.6 ppm for *Avena* coleoptiles (*9*), and above 9 ppm for *Phaseolus* petioles (*10*).

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Perception of Ultrasound

Abstract. *Ultrasonic vibrations can be perceived as audible sounds when a piezoelectric transducer is pressed against certain areas of the human body. In the range of frequencies investigated (20 to 108 kcy/sec), the threshold of perception seemed to lie near the threshold of feeling (about 10^{-4} watt/cm^2), and the perceived audible sound appeared to be between 8 and 9 kcy/sec, as judged by six test subjects. The threshold of perception and the perceived frequency appear to be dependent upon the hearing characteristics of the individual.*

As a result of an early observation by one of us (C.K.) that ultrasonic vibrations can be perceived directly as audible sounds, a series of experiments was undertaken to learn more about this effect. Piezoelectric crystals were excited into vibration at frequencies above the audible range (above 20 kcy/sec), and the vibrations were detected or "sensed" through the skin and tissue of the experimenter.

Exposure to the ultrasonic energy was achieved either by pressing a vibrating crystal directly against the body or by coupling the vibrations through a column of water placed between the crystal and the skin. The intensity of the perceived sound was dependent upon the location of the source of ultrasonic energy on the body of the observer. In the case of direct contact between the skin and a vibrating crystal, the firmness of the contact and the manner in which the crystal was held were also significant. The best sensing locations for most of the subjects were the trapezius muscle at the back of the neck, the masseter, the sternocleidomastoid, and the area of the temporal bone, particularly over the mastoid element. However, the sound was also perceived when the crystal was held at various other points, including a position near the clavicle or even lower on the chest.

Depending upon the location of the crystal and the deviation from the crystal resonance frequency, the sound appeared to originate first in one ear and then in the other, even though the location of the crystal remained the same. The frequency of the perceived sound was difficult to identify accurately. Approximate measurements were made by listening simultaneously to the "ultrasonic sound" and to the normal sound produced by a nearby loud speaker. Among the six observers, the judgments of the perceived pitch varied considerably, apparently depending upon the hearing characteristics of the individual. The six subjects tested in the course of the original experiments all agreed that the pitch fell in the band between 8 and 9 kcy/sec. Further investigations are needed to establish correlation between the pitch and intensity of perceived ultrasound and the hearing characteristics of the individual.

The first series of experiments demonstrated that ultrasonic vibrations can be perceived as audible sound of about 8.5 kcy/sec over the ultrasonic frequency range from 20 to 108 kcy/sec (the range explored so far). Table 1 shows the crystal power input which can be sensed as a function of ultrasonic frequency. The ultrasonic power actually reaching the auditory nerve may be only a minute fraction of the crystal input power, which was in the range from 100 microwatts to a few milliwatts, as indicated in Table 1.

In order to compare the ultrasound power density with the power density associated with hearing and feeling sensations of ordinary sound, the measured ultrasonic threshold power was converted into power density by dividing the total crystal power by the area of contact. Figure 1 illustrates the result of such a comparison. The curve labeled "hearing acuity" represents the threshold of audibility of ordinary sound which varies from about 10^{-16} watt/cm^2 at the optimum frequency (3000 kcy/sec) to values in excess of 10^{-4} watt/cm^2 near the limits of the audio frequency range (20 to 19,000 cy/sec). In contrast, the "feeling" curve at the level of about 10^{-4} watt/cm^2 is relatively flat over the entire audio frequency range and lies below the "hearing" curve outside this range.

The ultrasound threshold curve obtained in the course of present experiments extends from 19 to 108 kcy/sec and appears to be a continuation of the usual "feeling" curve. Toward the higher frequency end of the curve the minimum detectable power density appears to rise approximately as the square of the frequency. This rise may be related to an increase with frequency of the rate of absorption of ultrasonic energy propagating through the body tissues from the point of crystal contact to the "ultrasound sensor," whatever it may be.

In another series of tests, several subjects were asked to match in intensity the sound heard through "normal" hearing means (earphones) with that produced by an ultrasonically vibrating crystal. The arrangement of the test apparatus is shown in Fig. 2. Both oscillators were identical, and both were amplitude modulated at 10 cy/sec.

Table 1. Threshold ultrasonic power detected by observers A and B (transducer held against mastoid element of temporal bone).

Frequency (kcy/sec)	Power (mw)	
	Observer A	Observer B
20.1	0.15	0.4
28.2	.3	.6
30.0	.1	.2
42.0	.75	
43.5	.2	.3
64	3.0	
65	1.0	3.0
67	1.0	0.75
70.1	1.5	
81.0	4.0	3.0
108.0	8.0	5.0

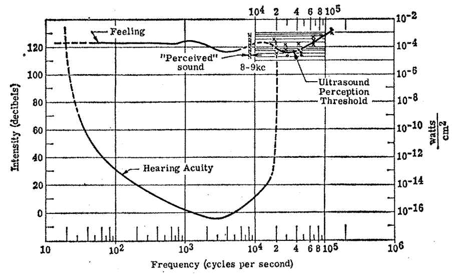

Fig. 1. Hearing acuity, feeling, and ultrasound perception thresholds.

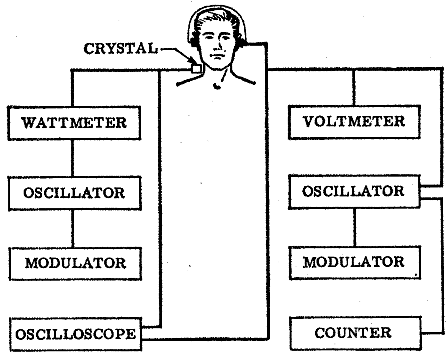

Fig. 2. Arrangement of apparatus for comparing normal sound intensity with that of ultrasonically produced sound.

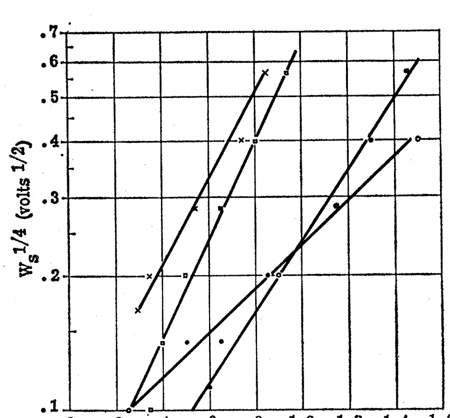

Fig. 3. Power required to produce "normal" sound intensity equivalent to that of the perceived ultrasound. Four subjects.

Each subject first adjusted the "normal" sound to the same frequency as that detected from the ultrasonic crystal transducer. The crystal was positioned for maximum perception sensitivity. Next, a determination was made of the minimum power levels at which each sound source could be heard. Thereafter the power to the earphones was increased by steps, and the subject adjusted the power to the crystal so as to match the sound intensity. From the results of these tests, which are shown in Fig. 3, it is of interest to note that for a given increase in the intensity of the perceived sound, the relationship of the driving power to the earphones and the crystal may be approximated by the expression

$$W_s = A \exp m(W_u/W_0)$$

where W_s is power to the earphones, W_u is power to the ultrasonic transducer, and W_0 is the minimum detectable ultrasonic power. The measurements indicated that m lies within the limits $m \approx 1.0$ to 2.5. W_s may be further defined as

$$W_s = V_s^2/R$$

where V_s is the voltage from the oscillator to the earphones and R, the impedance of the earphones, is 100 ohms.

Further experiments were performed on the perception of ultrasound which was intensity modulated at audio frequencies. It was very easy to sense square-wave or sine-wave modulation in the range 20 to 200 cy/sec with gradual fall-off toward 1000 cy/sec. This was partially explained by the limited bandwidth of the vibrating crystals, but further experimentation is needed to establish the effect of modulation on the intensity of the perceived sound and to measure the amount of intelligence which can be communicated by means of ultrasound.

It is believed that the direct perception of ultrasound depends upon the transmission of ultrasonic vibrations through the bones, muscle tissues, and blood and upon the stimulation of the auditory centers corresponding to the high-frequency channels of normal sound. The natural resonances of certain body structures may also be a factor in the production of the ultrasound perception effect. This effect is sufficiently large to make possible the detection of many resonant modes of a piezoelectric crystal. By simply pressing the crystal against his neck while sweeping the frequency spectrum with a variable frequency oscillator, the experimenter could locate weak resonances which the usual crystal resonance measuring circuit fails to indicate. Such weakly coupled modes were, of course, confirmed by more sensitive laboratory measurements.

A study of the mechanism by which ultrasonic vibrations over a wide frequency range are converted into an apparently constant band of audible sound suggests certain useful medical applications, such as in tests for certain types of deafness and, possibly, as a novel form of hearing aid. Also, in the field of communication, it is feasible by utilizing the ultrasound perception effect to devise signaling systems with unique performance characteristics for special purposes. Other possibilities will undoubtedly appear with further studies which will lead to a better understanding of the nature of the effect.

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Pattern of Uplifted Islands in the Main Ocean Basins

Abstract. *Most uplifted islands lie in one of three types of tectonic location: on mid-ocean ridges; between 200 and 750 km on the convex side of island arcs; and along a great circle across the southern Pacific, which may be a fault. Since the usual habit of islands is to subside, these islands may owe their uplift to their special tectonic positions. The regularity of this pattern of uplift supports the view that in the earth an elastic surface layer rests upon a plastic or viscous substratum.*

In 1842 Charles Darwin (*1*) suggested that the normal behavior of islands in the remote parts of the oceans is to subside and that during subsidence those lying in tropical waters pass through fringing reef, barrier reef, and atoll stages. After much debate, admirably reviewed in 1928 by Davis (*2*), Darwin's thesis seems to have been universally accepted. The results of drilling and recovering fossils from at least six islands, Funafuti, Bermuda, Bahamas, Daito, Bikini, and Eniwetok (*3–5*) support this view, as does the dredging and recovering of shallow-water fossils from the depths off at least Erben, Nazca, Hess, Cape Johnson, Sylvania, and Jimmu seamounts, and dredging off Providence and Tuamotu islands (*6*). Most of these data have been discussed by Kuenen (*7*) and Ladd *et al.* (*5*). No attempt is made here to consider the large literature on the possible structure of ocean basins, or the many ages determined on specimens dredged from the sea floor away from rises. All these ages are believed to be Cenozoic or Recent.

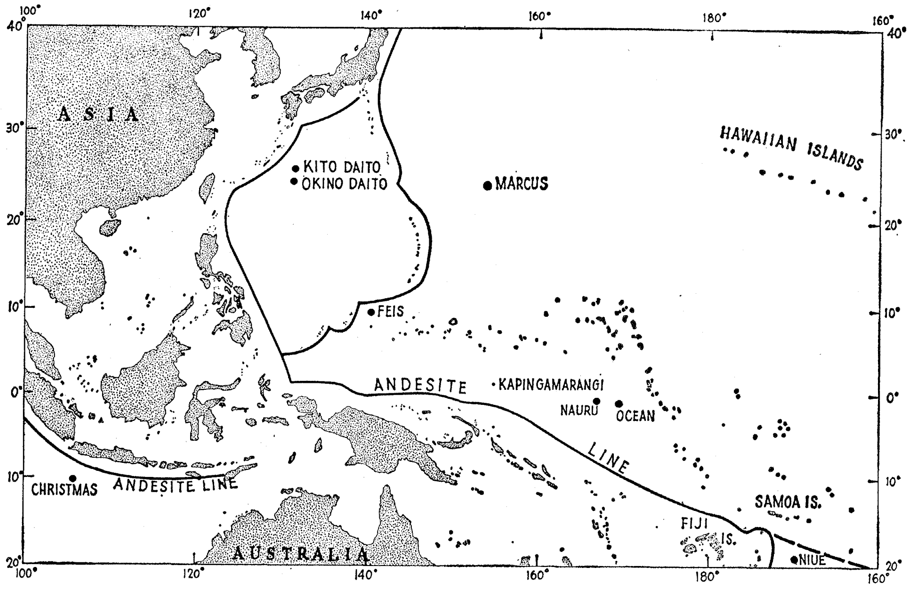

Fig. 1. Part of the western Pacific Ocean, showing eight uplifted islands. All lie close to the oceanic side of arcs or other parts of the andesite line.

It is apparent that all the islands investigated have sunk at average rates varying for different islands from 4 to over 50 m per million years. It is here assumed that sinking is the normal behavior of islands, that the cause is isostatic adjustment, and that the variation in rates is real.

An investigation of the literature reveals that a few exceptional islands, listed in Table 1, have been uplifted. This study has been limited to islands lying in the main ocean basins beyond continental shelves, island arcs, and the andesite line, for other factors enter into the behavior of islands within the border zones in young mountains and arcs. The very numerous references to islands that appear to have been uplifted by 6 m or less have been omitted, because a small lowering of sea level is known to have been universal since the climatic optimum 4000 years ago (*8*) and this is the cause of most of these cases.

Marine fossils found above sea level on some islands show that uplift has sometimes followed subsidence and terraces show that uplift has sometimes been intermittent. There is little point, therefore, in attempting to calculate average rates of uplift. It is more important to note that the amounts of uplift are in general much less than the amounts of subsidence. It is therefore easy to believe that uplift may be only a temporary and unusual state for islands. Tectonic disturbance seems to be the most likely cause of uplift.

The pattern of distribution of uplifted islands is of greater interest. It will be noticed that the first four islands in Table 1 lie on prominent ridges which are tectonically active. The next three groups of islands lie off the coast of Africa; I do not know either the amount or cause of their uplift. The next eight islands all lie immediately in front of active island arcs or close to active linear chains of Melanesia (Fig. 1). It is believed that the uplift of these islands is due to tectonic activity at the borders of the ocean basins. The depression of an ocean trench is considered to cause uplift of the ocean floor adjacent to it on the convex side. As a matter of interest the approximate distance of these islands to the nearest trench or border is given in Table 1.

The fact that Kapingamarangi and a few other atolls in the Caroline Islands equally close to the margin of the ocean do not appear to have been uplifted is not regarded as a valid argument against this hypothesis, because islands are known to sink at different rates and