limit is set as the critical pressure below which caisson disease does not occur, but many men have worked safely and endured rapid decompression at much higher pressures.

It is simple to suggest that the average whale is as capable in this respect as even the exceptional human diver. However, it is perhaps worth completing an argument which has been so often the cause of confusion. The danger of caisson disease specifically occurs when nitrogen diffuses so rapidly from the tissues that the critical pressure for bubble formation is reached in the blood vessels. To protect a man, the rate of diffusion is kept small by slow decompression, which reduces the gradient of nitrogen pressure from tissue to lung. The same result might be accomplished in the whale if the structure or composition of its tissues retards the rapidity with which nitrogen diffuses. For example, it is often suggested that the layer of blubber, with its large nitrogen solubility and meager vascularization, would provide for a slow escape of the nitrogen dissolved at high pressure. Corpulent human divers, however, are especially susceptible to caisson disease.

On the other hand, it is quite reasonable to point out Haldane's view that increasing the rate of the circulation removes the blood from proximity with the source of nitrogen before the critical pressure for bubble formation is attained. It is significant that the whale emerges from a deep dive with an oxygen debt and must maintain an active circulation of blood during the period of recovery. The human diver emerges with no oxygen debt and yet sufficiently fatigued to desire the rest which will further slow his circulation. The whale with an oxygen debt possesses likewise the essential conditions necessary for the specific stimulation of blood flow through the central nervous system,[6] and therefore with the precise conditions which are favorable to the avoidance of nitrogen embolisms in the susceptible central nervous tissue.

In reconsidering the situation in the diving whale, it is apparent that all the nitrogen contained in the lungs will be dissolved at about 4 atmospheres hydrostatic pressure, and that further submersion involves no greater physiological problem. Even to dissolve this amount of nitrogen requires the total collapse of lungs and thorax, a difficult process to reverse. But if it is possible and all the nitrogen is forced into solution, the amount present is still only three times as great as any human diver can safely eliminate. During decompression, the circulation in the whale is bound to be accelerated by the stimulus of its large oxygen debt. I believe that it is a conservative estimate that the whale's circulation would be three times as effective as the human diver's at the time of emergence from a deep dive.

In view of the limited supply of nitrogen and the favorable conditions of the circulation there is no reason why a whale with ordinary mammalian respiratory and cardio-vascular systems should be in danger of caisson disease. Any special characteristics of the whale, such as peculiar amount and distribution of the fat and the retina miriabilia, had better be kept in reserve for the solution of other problems of cetacean physiology.

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[6] W. G. Lennox and E. L. Gibbs, *Jour. Clin. Invest.*, 11: 1155, 1932.

THE HELMHOLTZ-KOENIG CONTROVERSY

IN 1870 Helmholtz published results showing that when two notes are sounded on a siren there are waves set up which will produce resonance in tuned Helmholtz resonators. Koenig repeated the experiment, using tuning forks, and failed to produce vibrations in a third tuning fork which was tuned to the difference tone. It is a well-known fact that when two notes are sounded we hear beats whose pitch is the difference between the two original notes.

The controversy which was argued pro and con for twenty-five or thirty years was: Are these tones which one hears due to a vibration or wave in the air or are they subjective tones? If there are waves in the air which produce vibrations in tuned resonators, strings or forks they are called combinational tones. If these waves do not exist in the air the effects in the ear are called beat notes. It seems that both sides of the controversy agreed as to the above distinction between combinational tones and beat notes. There was no quibbling or haziness about definitions. Present-day writers often use the terms beat notes and combinational tones interchangeably. Others seem to make a distinction between the two terms, but the distinction is a matter of pitch. If the pitch is less than 16 or 30, perhaps, the term beat note is applied. If more than 16 or 30 they are called combinational tones.[1]

All experimenters who used sirens and kindred apparatus were thoroughly convinced that combinational tones were a reality. All those who used tuning forks or piano wires as sources were convinced that there were no waves or combinational tones and that the effects were beat notes. Helmholtz and his followers said Koenig and his followers were wrong. Koenig and his group said that Helmholtz was wrong.

Rucker and Edser,[2] using a siren as sources and a tuning fork as a detector, found combinational tones, but when their sources were tuning forks they say they did not find combinational tones. However, they do

[1] Sutton, SCIENCE, March 8, 1935, p. 255.
[2] *Phil. Mag.*, 39: 341, 1895.

not seem to give much significance to this fact. They are sure there are combinational tones.

Hazel[3] shows that both sides were right, experimentally, and that both sides were wrong, in that they did not recognize that there is an underlying fundamental principle of wave motion in the experiments.

Koenig tried to add two sine waves and found nothing but the two parent waves. Helmholtz modulated one wave or frequency with a second wave and found combination tones. In Koenig's work the equation is, $A_1 \sin \omega_1 t + A_2 \sin \omega_2 t = ?$ Mathematically and experimentally, the only frequencies or waves found are the two original frequencies. In Helmholtz's work we may assume that the output is affected by the air pressure in the common air chamber or that the output is proportional to P sin ωt. When two orifices in the siren are open, the pressure at orifice No. 2, say, is $P_0 + P_1 \sin \omega_1 t$ (the pressure varies in unison with the frequency of orifice No. 1). Then the output is, $(P_0 + P_1 \sin \omega_1 t) \sin \omega_2 t$. Thus we have a "product term." The "product term" is shown by mathematics to be two frequencies, the difference and the sum of the two parent frequencies.

Hazel has shown that in every case when the "product term" is present we find combinational frequencies. These combinational tones or frequencies or waves are real waves which can be detected by tuned apparatus.

With the simple addition of waves these combinational waves are not present, and in the case of sound we have beat notes in our ears. However, if the two frequencies or waves are added through non-linear apparatus we have a "product term," and the combinational waves are found. In the case of sound, since we hear beat notes, the logical conclusion is that our ears are non-linear.

Hazel's work clears up the prevailing hazy conceptions of addition and modulation of waves and shows that the two operations are not the same and that they are fundamentally different.

The case of beat notes is somewhat the reverse of the physiological question: "If a tree falls in the center of a vast forest where there is no animal life, is there any sound?" Physicists will agree that there are waves in the air. There are waves but no ears. With beat notes there are ears but no waves—no air waves whose frequencies are the frequencies of the beat tones heard.

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GONADECTOMY AND A NEW SECONDARY SEXUAL CHARACTER IN FROGS

AN extraordinary and entirely new secondary sexual character in tailless amphibians has recently been described by Dr. C. C. Liu, of Soochow University.[1] This structure, the morphological relationships of which are fully described by its discoverer in a recently published paper,[2] consists of a band of connective tissue extending the entire length of each layer of the Obliquus muscle, at both their dorsal and ventral borders. In certain species at least, the ventral bands are continued inward toward the midline at certain of the inscriptiones tendinae. These bands have been named the *Lineae Masculinae*. As with many other sex-limited modifications in Amphibia, the functional significance of these structures is not immediately apparent. The most obvious assumption—that they are concerned with the mechanics of voice production—is rendered doubtful by their complete absence in many species that are excellent singers. They are found, among other species, in sexually mature males of the common American and European ranids, but are lacking in the bufonids of these regions, and are not found in females of any species. Parker[3] has erroneously stated that they are confined to the two species of *Kaloula, borealis* and *manchuriensis*. Liu has been able to show that they occur in a great many species of the frogs and toads of the world.

It is curious that the presence of a structure as sharply defined as this should have escaped observation until now, particularly in an animal that has been subjected to the minute and continuous scrutiny that has been applied to the frog. Once seen, the lineae masculinae are immediately apparent when a male frog has been skinned. Thousands of students must have observed them unconsciously in American and European laboratories. That they should have escaped the searching eyes of the German anatomists of the last century is still more remarkable. Only the chance combination of a transparent skin and almost complete lack of sexual dimorphism in the Chinese frog *Kaloula borealis* revealed them to Liu. From this starting point he has traced them through the Salientia of the world.

The restriction of the lineae masculinae to one sex suggests a correlation of some kind between them and the gonadal hormones. Their absence in sexually immature animals and an apparent lack of seasonal variation are also significant. As a rule, sexual dimorphism in frogs and toads is not great. The most obvious sex-limited characters are the growths, asperities and glandular accretions which have achieved

[3] *Phil. Mag.*, p. 103, January, 1935.

[1] C. C. Liu, "Secondary Sex Characters of Chinese Salientia." Thesis, Cornell University, 1934 (abstract, 6 p.).

[2] C. C. Liu, "The 'Linea Masculina,' a New Secondary Sex Character in Salientia." *Jour. Morph. Physiol.*, 57: 131–145, 1935.

[3] H. W. Parker, "A Monograph of the Frogs of the Family Microhylidae," London: British Museum, 1934.