listens with one ear to a combination of two pure tones. One is a loud 100-cycle tone, the other is a weaker 200-cycle tone. A phase relation between the two tones can be found such that the loudness of the two tones together is about one decibel less than the loudness of the fundamental alone. This is an example of the steady tone phase effect, in which a fundamental and one of its harmonics are heard together, the phase relation between the tones, as well as the pressure level of the harmonic, being subject to arbitrary control by the observer.

This effect was studied with a fundamental of 100 cycles kept at a sound pressure level of 104 db above 0.0002 dyne/cm^2. Harmonics up to the fifth were used, with particular emphasis on the second and third. Measurements of the phase of the harmonic sound pressure giving minimum loudness averaged approximately 180° for the second harmonic and 0° for the third (epoch angle of cosine functions relative to fundamental). Loudness measurements at these phase settings showed the loudness of the combined fundamental and harmonic to be about 1 db less than that of the fundamental alone. 180° from the phase of minimum loudness the loudness of the combined tones was about 1 db greater than that of the fundamental alone. The variation of quality with phase relation was also studied.

Interesting variations between observers were investigated and attributed partly to psychological and physiological differences in individuals. But consideration of all the data obtained points to the conclusion, supported by theory, that the phase effect is a more complicated phenomenon than has commonly been assumed. Since this effect has been the basis for many studies of subjective tones, the concept of subjective tones is analyzed and interpreted in a new light.

10. The Nature and Origin of Aural Harmonics. E. B. Newman, *Swarthmore College* and S. S. Stevens, *Harvard University*. (20 min.)—Problems as to the nature and origin of the aural (subjective) harmonics, tones which are heard, but which are not present in the sound wave outside of the ear, have concerned musicians and scientists for many years. It is customary to assume that these harmonics arise because of non-linearity in the functioning of the middle ear. Their magnitudes have been measured by indirect means, such as the method of best beats, but there has been no adequate direct study.

We have used several means to attack this problem. (1) The minimum amount of distortion (2nd harmonic) which the ear can detect in a tone was studied by determining the thresholds for the second harmonic when it is added, outside the ear, to a pure fundamental in various phase relations. (2) Since it is possible to pick up from the cochlea an electrical potential which gives a good indication of the functioning of the auditory mechanism, we made an analysis and measurement of the harmonic components present in the cochlear response of animals under normal and certain abnormal conditions. (3) The phase relations of the harmonics in the cochlear response were determined with the aid of a cathode-ray oscillograph. (4) Externally generated harmonics were added to the fundamental in various phase relations both for human and animal subjects.

The results show that, for purposes of analysis, we can distinguish two sources of aural harmonics. The odd harmonics arise, from non-linearity, when the amplitude of vibration approaches the elastic limit of the ear. The even harmonics are due to an asymmetry produced by tension of the muscles of the middle ear, and consequently, their magnitudes can be experimentally controlled.

Professor Hallowell Davis aided in the work on animals.

11. A Scale for the Measurement of the Psychological Magnitude Pitch. J. Volkmann and S. S. Stevens, *Harvard University* and E. B. Newman, *Swarthmore College*. (20 min.)—A subjective scale for the measurement of pitch was constructed from determinations of the half-value of pitches at various frequencies. This scale differs from both the musical scale and the frequency scale, neither of which is subjective. Five observers fractionated tones of 10 different frequencies at a loudness level of 60 db. From these fractionations a numerical scale was constructed which is proportional to the perceived magnitude of subjective pitch. In numbering the scale the 1000-cycle tone was assigned the pitch of 1000 subjective units (mels).

The close agreement of the pitch scale with an integration of the differential thresholds (*DL*'s) shows that, unlike the *DL*'s for loudness, all *DL*'s for pitch are of uniform subjective magnitude. The agreement further implies that pitch and differential sensitivity to pitch are both rectilinear functions of extent on the basilar membrane.

The correspondence of the pitch scale and the experimentally determined location of the resonant areas of the basilar membrane suggests that, in cutting a pitch in half, the observer adjusts the tone until it stimulates a position halfway from the original locus to the apical end of the membrane.

Measurement of the subjective size of musical intervals (such as octaves) in terms of the pitch scale shows that the intervals become larger as the frequency of the mid-point of the interval increases (except in the two highest audible octaves). This result confirms earlier judgments as to the relative size of octaves in different parts of the frequency range.

12. On Hearing by Electrical Stimulation. S. S. Stevens, *Harvard University*. (20 min.)—The well-known fact that the ear generates an electric potential in response to stimulation by a sound wave has its counterpart in the fact that, when an alternating current is passed through the head, an auditory sensation results. The observer hears a tone whose pitch is determined by the frequency of the alternating current.

Measurements were made of the power needed to elicit a sensation using currents of various frequencies. The power, rather than the simple voltage or current was measured, because the body presents a complex impedance to the current. The total impedance, when the electrodes are applied in a standard manner, decreases with increasing frequency. The power factor varies slightly with frequency. When the power is increased about 20 db above the thresh-