De ontwikkeling van spectrale weging zoals A, B en C bij meten en beoordelen van geluid

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TU/e, Human-Technology Interaction

NAG, masterclass geschiedenis
27 November 2019

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Where innovation starts

My relation to history of acoustics

- **Genuin interest since beginning of my career**
- **Stimulated by**
  - **Working since 1977 in three institutions with long-lasting history (libraries!!) in the field: Goettingen, IPO, Natlab**
  - **Work of my late wife in history and theory of science**
- **Since 1998: Small project funded by the DEGA (history of psychoacoustics in Germany 1900-1950)**
- **Several structured sessions at conferences (NAG/DAGA 2009, ASA/FA 2017, ICA 2019)**
- **Since 2009 Ass. Editor at Acta Acustica for History**

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My talk

- **When and how did the idea of spectral weighting come up?**

- **What were the application domains?**

- **Relation to the definition of the dB**

- **Not in my focus: Ongoing discussion of using different weightings, e.g. at different levels**

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A very informative modern source

A review of the history, development and application of auditory weighting functions in humans and marine mammals

Dorian S. Houser,[1] William Yost,[2] Robert Burkard,[3] James J. Finneran,[4] Colleen Reichmuth,[5] and Jason Mulsow[1]

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But, focussed on the US

Almost all of the initial research related to auditory weighting functions was performed at the Bell Laboratories from the early 1920s to the 1950s (Gertner, 2012; Yost, 2015). Many

1920s. The first detailed measures of sound level, and hence the beginning of the use of weighting functions, started at the Bell Laboratories at this time (Gertner, 2012).

This view ignores (a.o.): Extensive work on absolute threshold and loudness measurements, e.g. in Dresden, in 1920's

Patented loudness meter, produced by Siemens & Halske since 1926, by Barkhausen, based on loudness comparison

Sound analysis work done at Siemens research lab

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The way towards the dB

- **The decibel (dB) as logarithmic unit has two roots**
  - **Psychology: Weber-Fechner law about sensitivity to changes in level. Just noticeable differences are equal to a proportion of the reference value**
    → percept ~ log (stimulus strength)
  - **Engineering: Transmission power loss in telecommunication was expressed as "mile of standard cable"**
  - **This unit was in 1924 (within the Bell system of telephone services) replaced by TU (transmission unit)**
  - **TU as power ratio had the same definition as the dB as we know it (log base 10)**
  - **Next to it, the Neper existed as ratio for field (linear) quantities based on the natural logarithm**

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The way towards the dB II

- **Shortly after this (in the mid 20's) the term TU was renamed as decibel (to honor Alexander Graham Bell)**
- **The dB was recommended only for ratios (of pressure, intensities), but not as absolute value (like dB SPL)**
- **1 Np = 8.7 dB (log e ≈ 0.435)**
- **Absolute (logarithmic) scales were based on the absolute threshold of hearing, 10^{-16} W/cm^2 → 20 μPa**
- **Into the 30's, this scale was called phon (in German)**
- **Confusingly, in the '20's and '30's also deviant reference threshold pressures were in use**
- **20 μPa was adopted as standard in the US in 1936**

The second ingedient: Threshold values as function of frequency

- **Level measurement became only reliable in the 20th century.**
- **Early famous measurement by Max Wien in 1903**

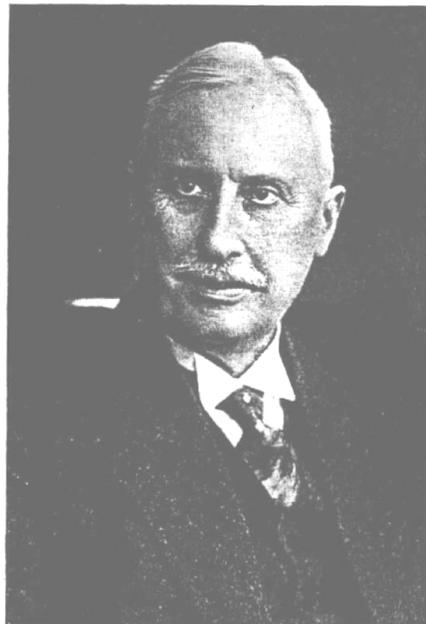

Foto: A. Bischoff, Jena

M. Wien

(Aus dem physik. Institut der technischen Hochschule Aachen.)

Ueber
die Empfindlichkeit des menschlichen Ohres
für Töne verschiedener Höhe.

Von
Max Wien.

(Mit 12 Textfiguren.)

Inhalt.

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II. Versuche, bei denen die Tonintensität an der Tonquelle gemessen wurde	20
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Pflügers
Archiv der
Physiologie,
Bd. 97, 1-57

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His results

- **His resulting curve**
- **X-axis: frequency logarithmically (50 – 12000 Hz)**
- **Y-axis: energetic measure, logarithmic scale**
- **Each number is a factor 10 step**

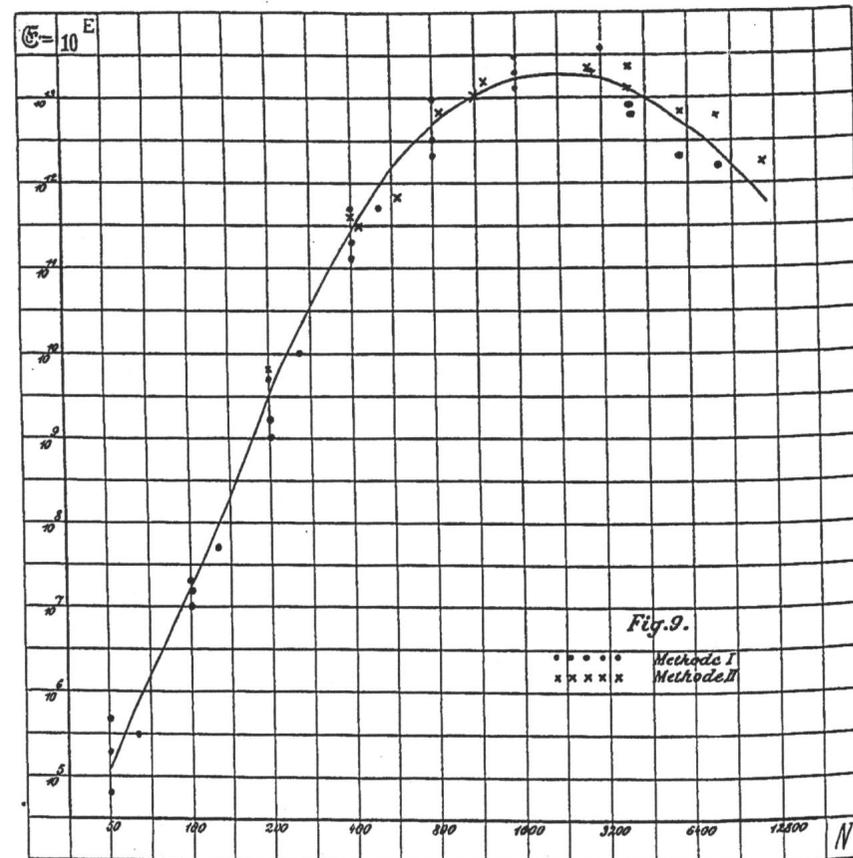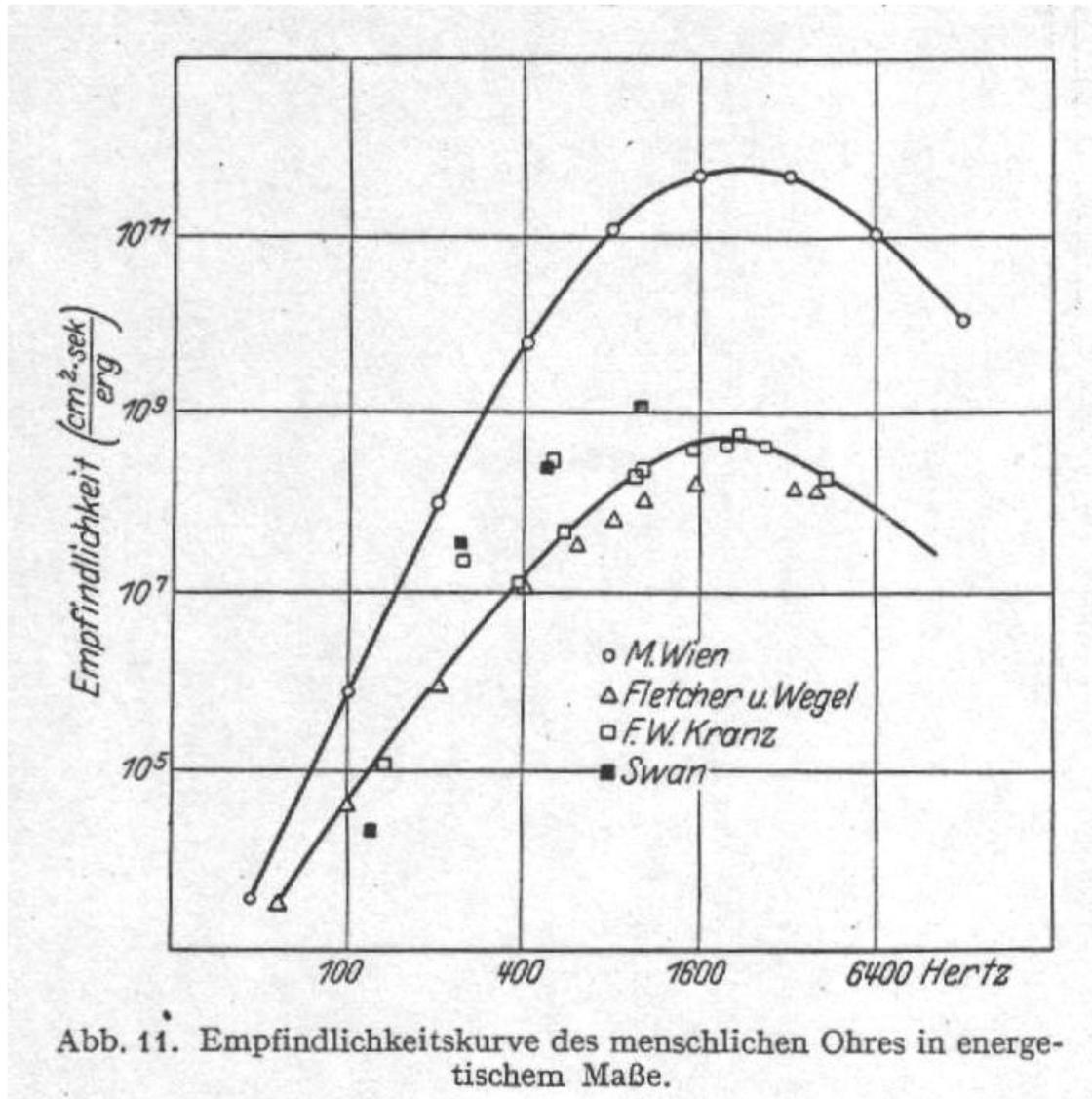Curve II berücksichtigt sind. Curve III ist also nun die

Fig. 9.

definitive Curve, durch die nach sämmtlichen Versuchen die relative Empfindlichkeit normaler Ohren dargestellt wird. In Fig. 9 ist sie nun noch-

Comparison with later measurements

Abb. 11. Empfindlichkeitskurve des menschlichen Ohres in energetischem Maße.

Erwin Meyer, 1928

The sensitivity is frequency dependent

- **Here comes the parallel with vision and optics**
- **Also the eye has such a frequency-dependent sensitivity**
- **This is characterized by the luminosity (efficiency) function**
- **First standardisation in 1924**
- **Photometric quantities (like luminance) are weighted, in contrast to radiometric quantities**
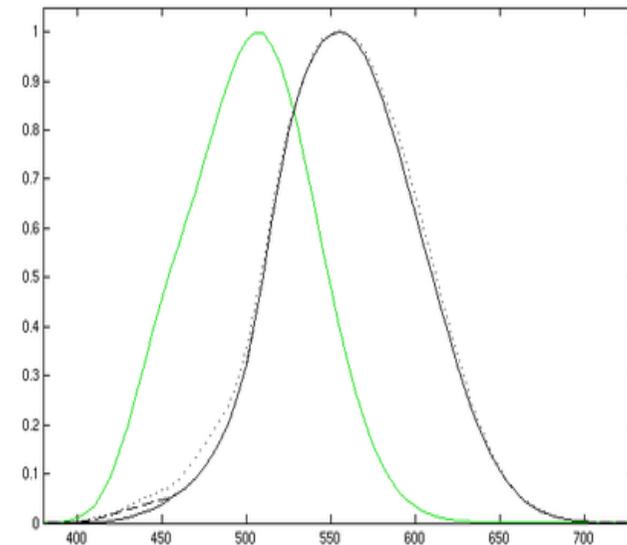
Photopic (black) and scotopic (green) luminosity functions. The photopic includes the CIE 1931 standard (solid)… The horizontal axis is wavelength in nm. Source: Wikipedia

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The first two technical implementations of spectral weighting; parallel developments

- **Rogers S. Galt (Bell labs); in JASA vol. 2 (1930). Context: outdoor noise surveys**

- **Ferdinand Trendelenburg (Siemens Research lab, Berlin); earliest source from 1929, Z. fuer technische Physik: recording and oscilloscopic presentation of low-frequency body (heart) sounds (auscultation)**

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Example Galt

RESULTS OF NOISE SURVEYS
PART I. NOISE OUT-OF-DOORS

By Rogers H. Galt

Bell Telephone Laboratories

[1] The other papers in the series "Results of Noise Surveys", presented before the Acoustical Society of America, May 9, 1930, are:

Part II—"Noise in Buildings"—R. S. Tucker
Part III—"Vehicle Noise"—J. S. Parkinson.
Part IV—"Noise Reduction"—J. S. Parkinson.

JASA vol 2 (1930), pg. 30 -- 58

Description of noise measurements

A different type of observation, employed in recent surveys, is independent of the observer's ear and yields a purely physical measurement. The apparatus consists of a pick-up device, or microphone; an amplifier, with or without a frequency weighting network, a distortionless attenuator; and a rectifying device with a meter. In some cases, a series of band-pass filters is arranged for insertion between two stages of the amplifier. The instrument may be calibrated for a particular type of noise by noting the meter reading when the noise is at the threshold of audibility; any greater reading of the meter gives the level

Description II

The frequency weighting network employed in some noise meters is so adjusted that the overall characteristic of the system for single frequencies is as shown in Fig. 2. This characteristic is based upon that of the normal ear,[6] the significance of which may thus be expressed: if a certain meter reading results when a pure tone of 1000 cycles at a sensation level of 30 units agitates the microphone, then the same meter reading will be obtained for any other pure tone of equal loudness.

Description III

SINGLE FREQUENCY CHARACTERISTIC OF NOISE METER
WEIGHTING NETWORK BASED ON EQUAL LOUDNESS
CURVE FOR NORMAL EAR AT 30 SENSATION UNITS
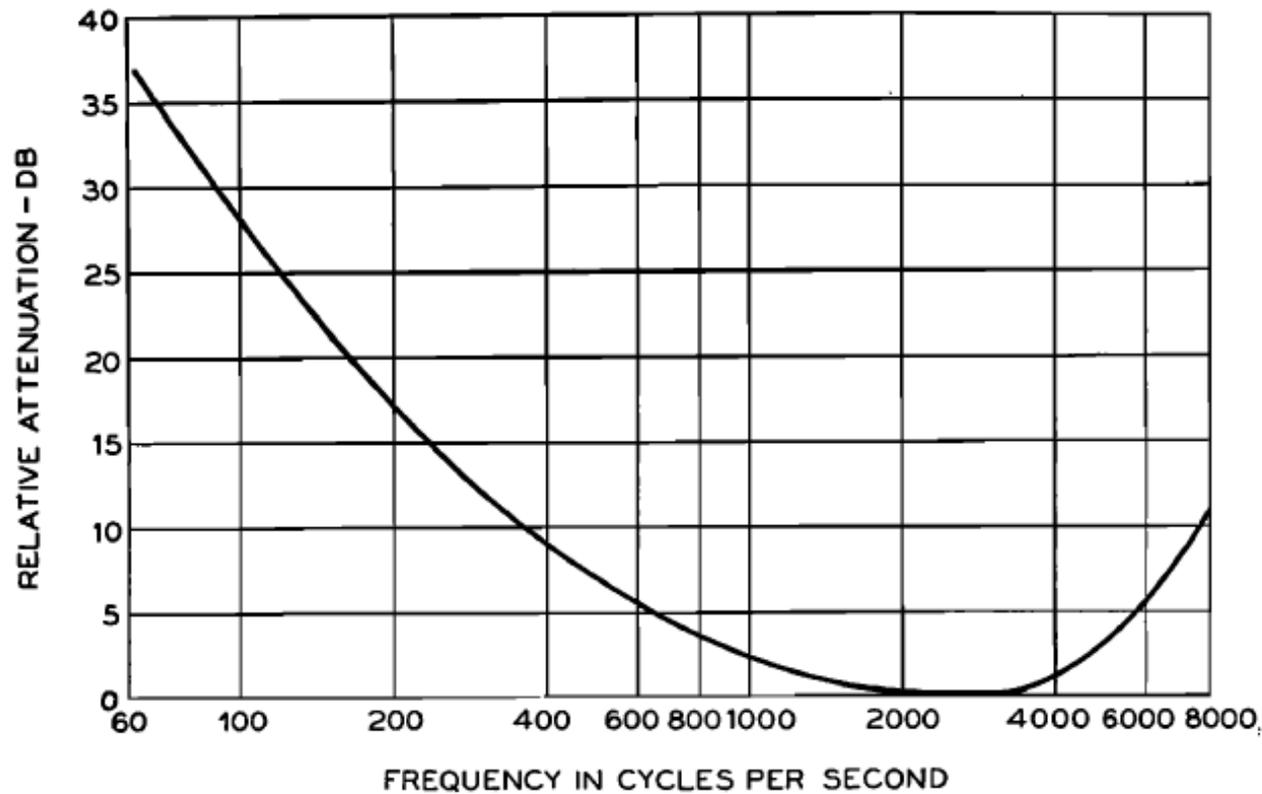
Emphasizing the limitations, already in 1930

the reading of the noise meter changes 10 decibels. It is well known, however, that a change of 10 decibels in intensity produces unequal changes in loudness at different frequencies; hence the noise meter cannot be said to measure the loudness of a pure tone at other levels than that for which the weighting network was adjusted. The meter

Ferdinand Trendelenburg (1896 – 1973)

- **One of the severely underrated acousticians of the interbellum period**
- **Extensive work of waveform analysis (Fouriertransform of recorded sounds) and time analysis of speech, music, environmental sounds**
- **Three books on acoustics in the 1930's**
- **Comparison of subjective and objective representation of sound**
- **Here the example of recorded heart sounds**

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Trendelenburg, 1931

- **Automatic registration of heart sound signal (auscultation) on an oscilloscope**

- **Discrepancy between visual representation and auditory experience:**

- Es ist ohne weiteres klar, daß der Arzt gegenüber einer derartig „falschen" objektiven Aufzeichnung, die sich mit seiner subjektiven Auskultation gar nicht deckt, größtes Bedenken haben muß.

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Diagnostically irrelevant first heart tone, 50-100 Hz
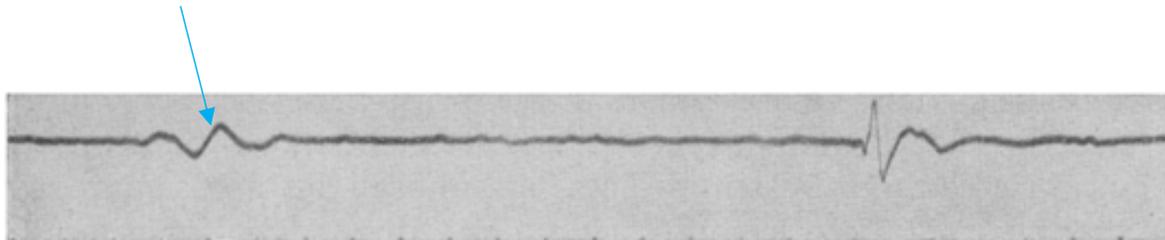

Fig. 2a. Herzgeräusch (physikalisch objektiv aufgezeichnet).
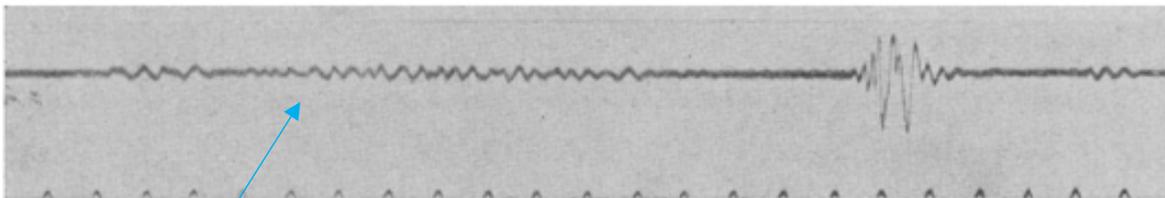
2a: Physically objective registration

Fig. 2b. Herzgeräusch (mit gehörähnlich arbeitendem Verstärker aufgezeichnet).

2b: Perceptually-motivated registration

Diagnostically relevant heart sound, 150-300 Hz

Curves of spectral weighting, 1931

1dyne/cm^2=0.1Pa
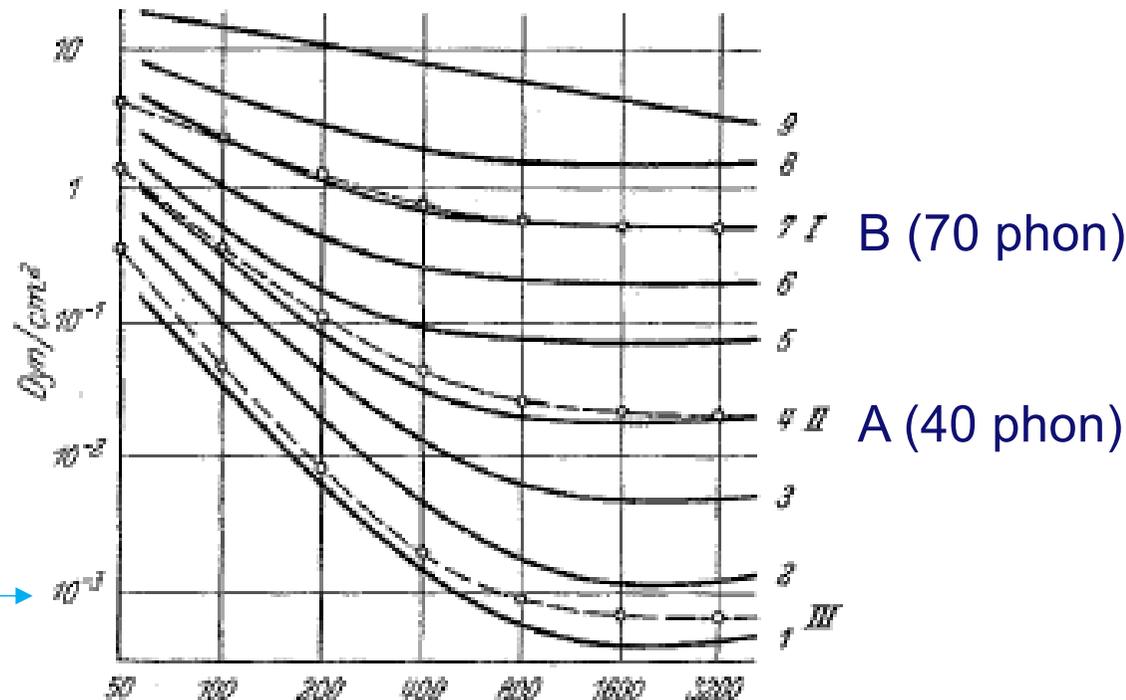
B (70 phon)

A (40 phon)

14 dB SPL

Fig. 3. Kurven gleicher Lautstärke (1—9) nach B. A. KINGSBURY und Kurven gleicher Verstärkung des gehörähnlich arbeitenden Verstärkers (I—III).

B.A. Kingsbury: A direct comparison of the loudness of pure tones. Phyisical Review, vol. 29, April 1927, pg. 588 -- 600

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Same concern about level dependence

Der Frequenzgang der Ohrempfindlichkeit ändert sich stark mit dem Lautstärkerniveau. Die Kurven gleicher Lautstärke sind — nach den Messungen von B. A. KINGSBURY[2] — in Fig. 3 eingetragen. Man erkennt, daß bei hohem Intensitätsniveau die Kurven gleicher Lautstärke wesentlich flacher laufen als die tiefste Kurve, die Schwellenwertkurve der Hörempfindung. Will man Messungen im gesamten Hörbereich durchführen, so muß man also den Frequenzgang der Meßapparatur entsprechend den Lautstärken einstellen. Die Einrichtung

The final step

- **In 1933, Fletcher and Munson published their more precise equal-loudness data in JASA**

Loudness, Its Definition, Measurement and Calculation

HARVEY FLETCHER AND W. A. MUNSON, *Bell Telephone Laboratories*

(Received August 28, 1933)

- **1936 – American National Standards Institute (ANSI) adopts the A-weighting curve based on Fletcher-Munson research in standards for sound level meters**

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