

Mach's Popular Lectures about Acoustics

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Introduction

Ernst Mach was an outstanding physicist, in addition, he was a great teacher, not only with regard to his students, but he also tried to reach a broader public. The aim of this contribution is to give some insight in the way how Mach popularised physics, and secondly, whether we can learn something from it: Is it already outdated or can one adopt or at least adapt some of his methods?

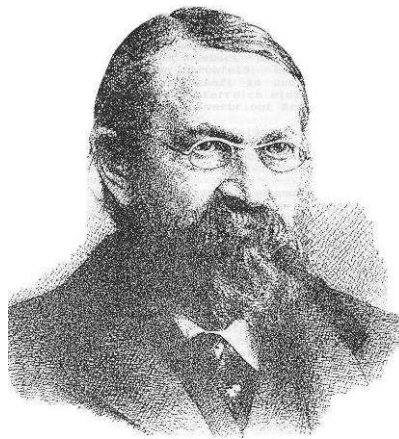


Figure 1: Ernst Mach (1838 - 1916)

Popular Lectures

Ernst Mach gave many lectures in front of general audiences. He published some of these lectures, interestingly for the first time in 1895 in English by an editor in Chicago. This editor visited Europe, listened to popular lectures of Mach in Prague, and was so impressed that he offered to publish these lectures with the title “Popular Scientific Lectures”. One year later, 1896, the first German version “Populärwissenschaftliche Vorlesungen” was printed, immediately followed by further editions. Figure 2 shows the front page of the fourth edition (decorated in the style of Art Nouveau). Mach died 1916, and 1923 his first son, Ludwig Mach, edited the fifth edition [1] which has been reprinted by an Austrian publisher in 1987 [2].

To gain insight into the philosophy of Mach with regard to popular lectures, I will cite from his preface. I will present the German original together with my English translation – the German original, because Mach used a wonderful language, which at least some of the readers will appreciate.

Popular lectures, because of the presumed knowledge (of the audience) and the limited time available, can have an instructive effect just in a modest way.

Populäre Vorlesungen können mit Rücksicht auf die vorausgesetzten Kenntnisse und die zur Verfügung stehende Zeit nur in bescheidenem Maße belehrend wirken.

Instruction seems not to be the first aim of Mach's lectures.



Figure 2: Front page of the fourth edition of Mach's popular lectures.

Therefore, one has to choose easier subjects and has to restrict one's presentation to the simplest and most essential points.

Dieselben müssen zu diesem Zweck leichtere Stoffe wählen und sich auf die Darlegung der einfachsten und wesentlichsten Punkte beschränken.

So, in Mach's opinion, not everything can be taught in this way, and it should be well prepared. But what is the purpose of the lectures?

*Nevertheless, by a proper choice of the subject one can transmit a feeling of the **romance** and **poetry** of research.*

*Nichtsdestoweniger kann durch geeignete Wahl des Gegenstandes die **Romantik** und die **Poesie** der Forschung fühlbar gemacht werden*

Mach's main aim is to transmit what it means to do scientific research, what a great and exciting enterprise it can be. The emphasis on the words romance and poetry has been made already by Mach.

For this purpose it is necessary to present the attractive and exciting elements of a problem, and to show how the light emanating from an inconspicuous clarification can illuminate a broad field of phenomena.

Hierzu ist es nötig, daß man das Anziehende und Spannende eines Problems darlegt, und zeigt, wie durch das von einer unscheinbaren Aufklärung ausstrahlende Licht zuweilen weite Gebiete von Tatsachen erleuchtet werden.

Mach again expresses in a very colourful language that he wants to transport the core of scientific research, not so much a respective content.

Also, by demonstrating the similarity between everyday and scientific thinking, such lectures may prove profitable.

Auch durch den Nachweis der Gleichartigkeit des alltäglichen und des wissenschaftlichen Denkens können solche Vorlesungen günstig wirken.

The mentioned positive effect should be the following:

The audience thereby loses its shyness in front of scientific questions and acquires an interest in research which is so beneficial to the scientist.

Das Publikum verliert hierdurch Scheu vor wissenschaftlichen Fragen und gewinnt jenes Interesse an der Untersuchung, welche dem Forscher so förderlich ist.

Again: The most important point for him is to increase the public understanding for scientific research and, by this, to decrease the boundary between the two areas.

It might be of interest to confront Mach's aims with a recent view. Nuclear physics is a special branch of physics with its own community and interests, and with its special journal "Nuclear Physics News". One of the last issues [3] was devoted to "Outreach", which appears to be the modern word for popularisation. The following sentences are from the editorial of this issue:

Research and education are the two major activities of any science community but the strong supporting role of outreach is now widely recognized.

The next sentences explain the purpose of outreach:

Outreach helps research by informing the public and legislators who can enhance support for scientific enterprise. Outreach helps education, because students will be more motivated to pursue a science-based trajectory.

Isn't this in contradiction to Mach's view? Mach starts from his own enthusiasm and wants to share it with others. His audience is the broad public and his goal, in first instance, is not to recruit future physicists. As an example: On several occasions Mach gave very charming lectures for wives of officers of the Austro-Hungarian army.

Popular Lectures about Acoustics

When Mach was in Graz, he published a book "Introduction to the Theory of Music by Helmholtz" with the subtitle "Presented popularly for Musicians" [4]. He has given already before popular lectures on this subject, but it seems that he was not satisfied with them:

I encountered, however, immediately enormous difficulties. Those things that were quite important to me as scientist were taken with great indifference by the musicians, and even spoiled their taste for what would be useful to them.

Ich stieß jedoch hierbei bald auf bedeutende Schwierigkeiten. Gerade das, was mir als Naturforscher recht wichtig schien, wurde von den Musikern mit großer Gleichgültigkeit aufgenommen und verdarb ihnen sogar den Geschmack an dem, was für sie verwerthbar gewesen wäre.

Therefore Mach wanted to do it in a different way, and he stated his guidelines for this booklet as follows:

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| <ol style="list-style-type: none">1. <i>Any physical theory, not strictly pertaining to the matter, has been avoided.</i>2. <i>Even the most elementary calculation has been avoided as much as possible.</i>3. <i>Finally, only the most important points of Helmholtz' theory have been stressed. This is necessary so that the non-physicist does not lose the thread in the huge amount of details</i> | <ol style="list-style-type: none">1. <i>Jede nicht streng zur Sache gehörige physikalische Theorie wurde vermieden.</i>2. <i>Auch die elementarste Rechnung ist so viel wie möglich vermieden.</i>3. <i>Endlich wurden von der Helmholtz'schen Theorie nur die Hauptpunkte herausgehoben. Es ist dies nöthig, damit der Nichtphysiker bei der Masse der Details nicht den Faden verliere.</i> |
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Again, Mach stresses that only the most important facts should be presented, and just the absolutely necessary physical and mathematical framework should be used. But he admits that this task is not easy:

Since these lectures did cost me quite some thinking and efforts, and since only the eager cooperation of musicians and physicists can yield a perfect theory of music, I believe I have done something useful by publishing them. By this leaflet I just wanted to achieve the goal that some musicians lose their first reservation against studying the work of Helmholtz.

Indem mich nun diese Vorträge einiges an Nachdenken und einige Mühe gekostet haben und indem die Musiktheorie nur durch das eifrige Zusammenwirken der Musiker und Physiker zur Vollendung gelangen kann, glaube ich etwas Nützliches zu thun, wenn ich sie in Kürze veröffentliche. Ich wünsche auch mit diesen Blättern nicht mehr zu erreichen, als dass mancher Musiker die erste Scheu vor dem Studium des Helmholtz'schen Werkes überwinden möge.

So at the end, Mach is confident that it is worthwhile to popularise physical content, but, again, he is very modest in reaching his aims.

Consonance and dissonance

Finally, I will present one explicit example, namely Helmholtz' explanation of consonances and dissonances of chords. I will show Mach's way of simplification, and I will compare it with what can be done with modern means.

Mach explains dissonances by the appearing of beatings in the following way:

Beatings, if they become more frequent (appearing about 30 – 40 times a second), represent a very unpleasant phenomenon for the ear. They create some roughness and sharpness ... beatings are the reason for disharmony.

Die Schwebungen sind, sobald sie etwas rascher werden (etwa 30 – 40 mal in der Secunde eintreten), eine für das Ohr sehr unangenehme Erscheinung. Sie geben dem Zusammenklange etwas Rauhes und Scharfes... die Schwebungen sind die Ursache der Disharmonie.

The background of these statements were refined experiments, with tuning forks, with musical instruments. But it was almost impossible to show this in a public lecture. We can do this nowadays: Personal computers can be equipped with sound cards, software allows for an analysis of complex sound examples [5]. Figure 3 shows the visual representation of a tone being constant and one tone rising in frequency. The listener hears two distinct tones, when the frequencies are far apart. Beatings are clearly audible when the frequencies have a difference of just some Hertz. But one hears a sharp, unpleasant sound in the region which Mach addresses.

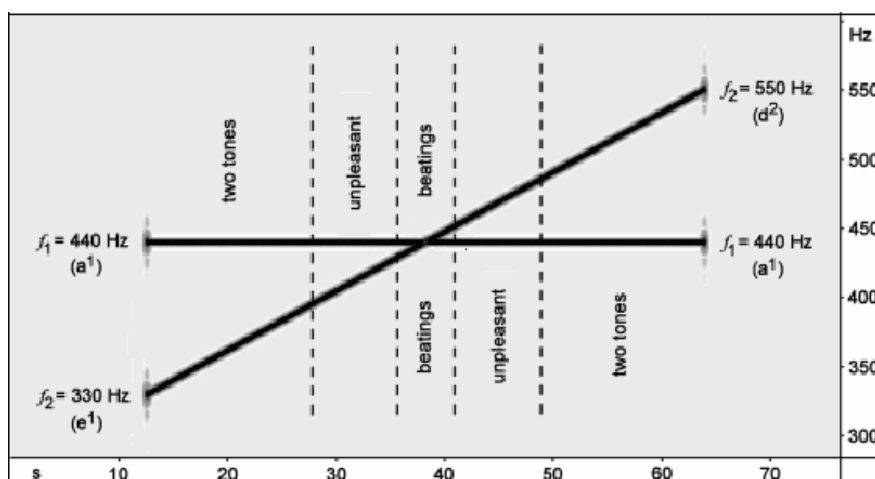


Figure 3: Visualisation of two tones and regions of different sensation.

Mach explains that the sensation of consonance and dissonance is connected to the beating between overtones.

Beatings are unpleasant when two interacting sounds are within an interval of one tone. When larger intervals create unpleasant beatings, they mostly originate in overtones. Sounds are the more related, the more and stronger partials coincide.

Die Schwebungen sind unangenehm, wenn die zusammenwirkenden Klänge weniger als ein Ganztonintervall von einander absteigen. Wenn größere Intervalle störende Schwebungen geben, so rühren diese meist von den Obertönen her. Klänge sind verwandter, wenn mehr und stärkere Theiltöne zusammenfallen.

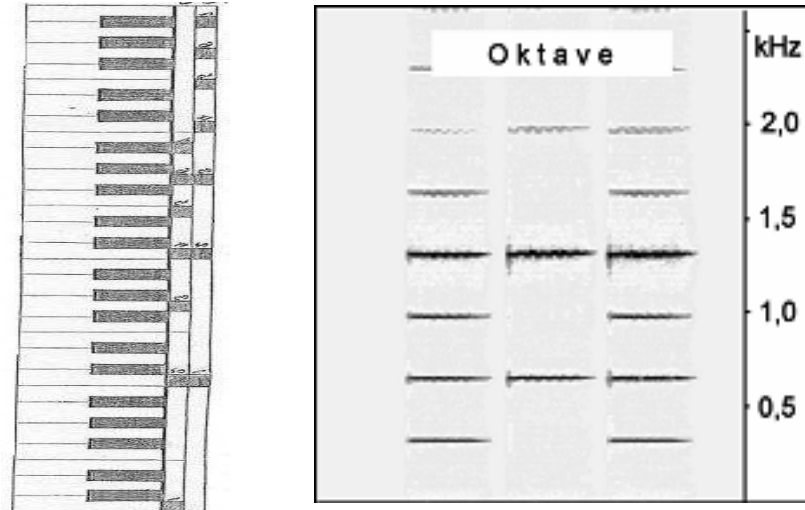


Figure 4: Superposition of two sounds which are one octave apart: Mach's visualisation (left) and output of a modern software (right). Note that the graph on the right has an absolute frequency scale, whereas Mach compares with a keyboard, i.e. uses a logarithmic scale for the frequency.

Figure 4 give Mach's illustration with the example of a keyboard on the left and the equivalent visualisation using an appropriate computer software [5]. Both presentations in Figure 4 try to explain the consonance of an octave by the relation of fundamental and overtones of the two sounds: some of the overtones coincide, none of the overtones are in the unpleasant region. Since Mach works with the picture of a keyboard, the overtones are not equally spaced as in the right graph which uses an absolute frequency scale.

Conclusion

Mach used all methods (experiments, graphical presentations) available at that time also for his popular lectures. He even invented experiments just for the purpose of explanations and presentations, for example the so called Mach's pipe in order to demonstrate the Doppler effect [6]. I am sure that Mach would have been delighted by the possibility to perform a Fourier transform of a complex sound on stage, in front of his audience.

He wanted to show and share his enthusiasm for science and research – and this with everybody. He believed strongly that people would profit by sharing some of this feeling. The message is important, not so much the topic, with which it is transported.

The selection of topics and the level of presentation has to be tuned to the audience. And one should try to elementarize as much as possible. He admitted that this is not easy, but it is worth the effort.

Nowadays, science is seen in a very objective, impersonalized way. Scientific papers usually don't use the words "I" or "we". The facts have to speak for themselves. This may be a proper way for scientific papers, but addressing a general public, one has to work from person to person. Mach did not hide his person. He expressed his personal feelings, his

enthusiasm and he wanted to share these emotions as well as his knowledge with others, independent of their formal education and status.

Ernst Mach was outstanding not only as physicist and philosopher, but also in his way of popularising physics. Mach contributed to formal education by the development of curricula for schools, he has also realized the importance of informal education of the public. Whereas the methods were constrained by the technical possibilities of the respective period, Mach's general approach seems to be timeless, and therefore worthwhile to be taken seriously also today.

References

- [1] Mach E 1923 *Populärwissenschaftliche Vorlesungen* (Leipzig: J. Ambrosius Barth)
- [2] Mach E 1987 *Populärwissenschaftliche Vorlesungen* (Wien: Böhlau Verlag)
- [3] Huyse M 2005 *Nuclear Physics News* 15(2) 3.
- [4] Mach E 1866 *Einleitung in die Helmholtz'sche Musiktheorie. Populär für Musiker dargestellt* (Graz: Verlag Leuschner & Lubensky)
- [5] The program CoolEdit (<http://www.syntrillium.com> or <http://www.adobe.com/special/products/audition/syntrillium.html>) has been used for sound-analysis and visualisation; it should be noted that there exist several, more or less, equivalent programs on the market, some of them even as free ware.
- [6] Mathelitsch L Verovnik I 2004 *Akustische Phänomene* (Köln: Aulis Verlag Deubner, Wien: Verlag öbv&hpt)