Emilie Těšínská

ERNST MACH, HIS PRAGUE PHYSICS STUDENTS AND THEIR CAREERS

Ernst Mach (1838–1916) worked at Prague University as Professor of Experimental Physics in 1867–1895. After the University split into two autonomous parts (Czech and German, in 1882), Mach continued as Professor at the German University. He was twice appointed Rector of the University - in academic years 1879/80 and 1883/84. A large number of students (aspiring to become secondary school physics teachers, pharmacists or medical doctors) attended Mach's lectures and the Institute of Physics during the 28-year period. Based on archives, written memoirs and literature on the history of science, this paper presents Mach's teaching activities in Prague and the careers of some of his Prague university students and assistants. Later university professors (in the Czech lands as well as in other parts of the Austro-Hungarian Monarchy), authors of physics textbooks or manufacturers of teaching aids and physics instruments can be found among them. Mach's work for the Prague (German) Association of Natural History "Lotos" is also mentioned as well as Mach's membership in the Association of Czech Mathematicians and Physicists and in the Royal Bohemian Society of Science.

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Emilie Těšínská

Introduction

Ernst Mach is, undoubtedly, one of the most significant individuals in the field of physics to have come out of the Czech lands and to have been active for a long time in this part of Europe. He was born in 1838 in Moravia, in the village of Chrlice near Brno, where he spent the first two years of his life. In 1852–1855, he completed his secondary school studies at the public Piarist Grammar School in Kroměříž, Moravia. The twenty eight years between 1867 and 1895 that he spent at the university in Prague were the most productive of his professional career.

Mach's Prague Professorship in Experimental Physics

Arrival in Prague

In his own biography written in 1913, E. Mach described his arrival in Prague in these words [1]: *„It was in April 1867 when I moved from cheerful, friendly Graz to beautiful, gloomy Prague, where my profession called to me."* Prague enchanted him with its history and monuments. Less attractive for him became Prague's atmosphere affected by the competitiveness between the Czech and German communities.

As opposed to Mach's previous three-year professorship at the university in Graz (without his own institute and corresponding subsidies, and where E. Mach more or less lectured mathematics), it appeared that Prague could provide him with more favourable conditions for his interest in physics. Prague was also attractive because of its scientific traditions, e.g., the recent activity of physicist Christian Doppler (1803–1854) and the presence of Czech physiologist Jan Evangelista Purkyně (1787–1869), however aged he was.

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E. Mach showed an interest in the Professorship in Physics at both Prague Polytechnic Institute and Prague University. In 1867, both these posts become free at once through the departure of physicist Viktor Pierre (1819–1886) to Vienna. Mach's application for the physics post at Prague Polytechnic Institute carries the date of 2 December 1866. The Institute was utraquistic at that time, with lessons given both in German and Czech. The vacant post E. Mach applied for had German as the language of tutorial. Nevertheless, to support his application, E. Mach indicated his ability to lecture in Czech as well. The total number of applicants was eleven. Adalbert K. Waltenhofen (1828–1914) from the University of Innsbruck was appointed to the position. E. Mach acquired the Professorship in Physics at Prague University.

A view of Prague taken by photographer F. Fridrich in 1865.

E. Mach's departure for Prague coincided with a significant step in his personal life as well. On 1 August 1867, he married Ludovica Marussig (1845–1919) in Graz. This marriage produced five children, all of whom were born in Prague.

The „wandering" of the university professors of the Austro-Hungarian Monarchy and the crossing of their paths can be illustrated by the scientific curriculum of Mach's contemporary and later colleague in Prague, physicist Ferdinand Lippich (1838–1913). In 1865, F. Lippich came to the Technical University in Graz from Prague Polytechnic Institute. In Graz, he acquired the Professorship in Theoretical and Applied Statistics and Mathematics. About five years later, in 1870, he returned to Prague. He became the Professor of Mathematical Physics at Prague University as the successor to mathematician Vilém Matzka (1798–1891), who had until that time also lectured mathematical

physics. F. Lippich was both a theoretician and experimenter. He worked mainly in the field of optics. He assembled, for example, a polarizing stroboscope (of great utility in sugar production). Together with mathematician Heinrich Durège (1821–1893), who came to Prague in 1864 from Zurich (to Prague Polytechnic Institute first, and then in 1869 to Prague University), F. Lippich stood at the head of the Mathematics Seminar, which represented a very important part of the university education of students aspiring to become secondary school teachers of physics and mathematics. He was active at Prague University and from 1882 at Prague German University until his retirement in 1910.

Heinrich Durège (1821–1893)

Ferdinand Lippich (1838–1913)

Teaching Activities at Prague University

Colleagues

The physicists E. Mach, V. Matzka and after him F. Lippich, the mathematicians H. Durège, his (Czech) colleague František Josef Studnička (1836–1903, at first a Professor at Prague Polytechnic Institute), and mathematician and astronomer Karl Hornstein (1824–1882, from 1868/69 director of the university observatory in Prague, Clementinum) formed the core of the staff of professors at the Faculty of Philosophy of Prague University for the fields of mathematics and physics at the turn of the 1860s and 1870s.

E. Mach began regular teaching at Prague University in the academic year 1867/68. However, he had been indicated (as the new head of the Physics Institute) within the staff of Prague University as early as in summer semester 1867.

Experimental physics lectured at the Faculty of Philosophy of Prague University was intended at that time for students aspiring to become secondary school teachers of mathematics and natural sciences groups (philosophers) and for students of the two-year courses in pharmacy (pharmacists). The rigorous guidelines from the 1850s had physics included among the examinable subjects (and thereby also included in the study plan) for the students of the Faculty of Medicine (medics). The number of medical students and pharmacists always appreciably exceeded the number of physics students from the ranks of philosophers at Prague University.

The schema of lectures and seminars in experimental physics offered by the Faculty of Philosophy of Prague University changed during the course of Mach's activities there – under the influence of modifications of the study regulations, with regard to the number of students and the teaching staff, with regard to the construction of new premises for the Physics Institute, and, naturally, also with regard to Mach's organizational duties and his scientific work. For a long time, only a two-year course in experimental physics for students aspiring to become secondary school physics teachers was offered instead of a four-year course (prescribed in 1867/68). As the complete list of lectures set down by E. Mach in each semester at Prague University can be found in literature [2, 3, 4], only a few small corrections and supplementary illustrations on this point will be given in this paper.

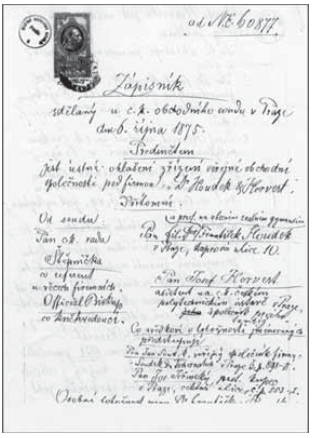
In the 1867/68 academic year (his first in Prague), E. Mach offered a two-semester course entitled *Grundlehren der Physik für Lehramtskandidaten* (4 lessons per week in the first semester and 3 lessons per week in the second). Under the shortened title *Physik*, 68 philosophers (48 Czech, 19 German, 1 Polish) signed up for it in the winter semester and 49 (38 Czech and 11 German) in the summer semester. Tied to this course was a seminar entitled *Praktische Übungen verbunden mit Besprechungen über ausgewählte Kapitel der Physik und Referaten über die neuesten Fortschritte* (4 lessons per week, on Saturdays), for which 53 philosophers (42 Czech, 10 German, 1 Polish) signed up in the winter semester and 30 (22 Czech and 8 German) in the summer semester (when, however, its title was slightly modified). In the winter semester of that year, E. Mach offered a separate 5-lesson course entitled *Physik für Pharmaceuten* for which 42 pharmacists (students of the first semester, 26 Czech and 16 German) signed up. In the winter semester, Mach also gave his first free *colegium publicum* (1 lesson per week) entitled *Besprechung über einige Hauptfragen der Physik*, for which 76 philosophy students (58 Czech and 18 German) signed up. In total, 136 winter-semester students and 86 summer-semester students of the Faculty of Philosophy signed up for the lectures of the new Physics Professor E. Mach. Approximately two-thirds of them stated their

nationality as Czech upon course registration. The predominance of students of Czech nationality corresponded to the nationality composition of the students attending Prague University at the time. They came mostly from the Czech lands. Thus, in the 1867/68 academic year, total of 1,442 students were enrolled at Prague University (among them 292 philosophers, 281 medical students, 66 pharmacists), – 1,308 came from Bohemia.

Among the students signed up for Mach's lectures and seminars in the first year of his working in Prague, we can find his later assistants Klemens (Mírumil) Neumann (in 1867/68, a student of the 3rd year) and Vincenz (Čeněk) Dvořák (a student of the 2nd year), as well as his future colleagues at the university, Karel Domalíp (a student of the 2nd year) and August Seydler (a student of the 1st year). In 1867/68, students of the first year and Mach's disciples also were Josef Hervert (1846–1883) and František Houdek (1847–1917). Soon after their university studies, in 1874, these two gentlemen established „Dr. Houdek & Hervert", factory for the production of physical instruments and metrical models. This was a continuation of the business started in 1870 by their senior university fellow M. Neumann, who died in 1873. Houdek and Hervert bought Neumann's factory in August 1874. The residential address of the factory was Prague, Kaprová street 10. In 1875, they published a price list of their products („Cenník továrny na fysikální stroje a měřické modely firmy Dr. Fr. Houdek a Jos. Hervert") comprising 1,275 items of physical instruments and models (plus some physical toys). This price list, however, was more than a simple business catalogue. In its time, it also represented an important aid for Czech physical terminology. From August 1874 to December 1874, the factory received 67 orders, mostly from schools in the Czech lands but there also were applicants from e.g. Vienna, Zagreb, Szeged, Cracow. Prof. E. Mach also belonged to their (satisfied) clients. Despite the death of J. Hervert in 1883, the firm continued under the leadership of Dr. F. Houdek (and then his son Otakar) until the mid 20th century. In 1925, the firm received permission to manufacture and sell radios as well. The business stopped before World War II and was deleted from the Commercial Register in 1951.

In the winter semester of the 1872/73 academic year, E. Mach offered for the first time an independent course of physics for medical students (*Experimentalphysik mit Rücksicht auf die Bedürfnisse der Mediciner*, 5 lessons per week) whereas the lecture for philosophers and pharmacists was held jointly (*Experimentalphysik für Lehramtskandidaten und Pharmazeuten*, 5 lessons per week). The lectures took place daily from Monday to Friday at the Physics Institute, for medical students from 10 to 11 a.m., for philosophers and pharmacists from 12 to 1 p.m. In the summer semester, however, the continuation of the course was attended by philosophers and medical students together again (*Experimentalphysik mit Rücksicht auf die Bedürfnisse der Mediciner und Lehramtskandidaten*, 5 lessons per week). The course was accompanied by the fundamental seminar in both semesters. In addition to that, the seminar *Anleitung zu wissenschaftlichen Arbeiten* for advanced students (free of charge for the *Lehramtskandidaten*) was offered by E. Mach in the summer semester. The number of students enrolled in Mach's lectures per semester increased with the medical students by 30–40 persons.

František Houdek (1847–1917)



Registration of the firm *„Dr. Houdek & Hervert"* at the Commercial Court in Prague (October 6, 1875).

In the winter semester 1872/73, there was announced (also for the first time) another (partly concurrent) course of physics at the Faculty of Philosophy of Prague University that was aimed at students of medicine. It was offered by M. Neumann, private lecturer of experimental physics and physical technique at Prague University (Mach's former student and assistant). The course was entitled *Nauka o světle pro mediky* [Science of Light for medical students] and given in Czech. It took place on Monday, Wednesday and Friday from 10 to 11 a.m. in Prague, Clementinum [25].

E. Mach had experience in teaching physics for medical students already from the university in Vienna. At Prague University, however, there were problems arranging for these classes at the beginning. Private lecturer, Doctor of Medicine Eduard Grégr, a former assistant of Professor J. E. Purkyně, gave lectures on Medical Physics and Animal Electricity (both in Czech and German) in the years 1860–1864. Mach's predecessor V. Pierre tried to promote the joint attendance of medical students, pharmacists and philosophers at his course in experimental physics then. Such a solution, however, was deemed inadequate by the Faculty of Medicine in terms of the specific requirements for the study of medicine. But the Faculty's own attempt at arranging physics lectures failed. Against joint lectures with pharmacists and medical students, as promoted by V. Pierre, were also philosophy students, as they believed that this arrangement would decrease the professional level of their classes. The names of V. Dvořák, K. Domalíp, and M. Neumann, can be found among the student signatures on the petition delivered on 1 December 1866 to the Academic Senate of Prague University and addressed to the Viennese Ministry of Culture and Education in this case. [5,19]

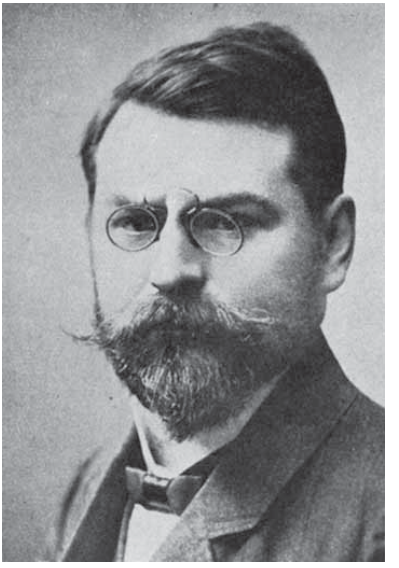
Winter Semester 1879/80		
II. Mathematische Wissenschaften		
Prof. H. Durège	Differential- und Integralrechnung*	3 (lessons p. week)
	Kurven im Raume und krümme Flächen*	2
Prof. F. J. Studnička	Über Determinanten*[x]	3
	Integration der Differentialgleichungen*[x]	2
Priv. Doz. Ed. Weyr	Über Flächen zweiten und dritten Grades*[x]	2
Priv. Doz. A. Puchta	Elliptische Functionen*	3
K. k. Astronom Prof. C. Hornstein	Analytische Mechanik in Anwendung auf die Bewegung der Himmelskörper*	2
III. Naturhistorische Wissenschaften		
K. k. Regierungsrath Prof. E. Mach	Experimentalphysik, I. Theil*	5 (Mo, Tu, Wed, Th, Fri) ; 12.30 to 13.30; Physics Institute (PhI)
	Theoretische Ergänzungen zur Experimentalphysik (Publice)	1 (Tu), PhI
Prof. F. Lippich	Theoretische Mechanik, insbesondere Kinematik*	3
	Dioptrik und Theorie dioptrischen Instrumente*	2
Priv. Doz. A. Seydler	Einleitung in die theoretische Physik (Gravitation, Magnetismus, Electricität)*[x]	3
Priv. Doz. K. Domalíp	Electricitätlehre in ihrer historischen Entwicklung*	1, PhI
	Experimental Physik (Electricitätslehre)*[x]	2, PhI
IV. Wissenschaftliche Seminäre; 2. Mathematisches Seminar		
Prof. H. Durège	Mathematische Übungen	2
Prof. F. Lippich	Mathematisch-physikalische Übungen	2
Sommer Semester1880		
II. Mathematische Wissenschaften		
Prof. H. Durège	Differential- und Integralrechnung, II. Theil*	3
	Analytische Geometrie des Raumes*	2
Prof. F. J. Studnička	Algebraische Analyse*[x]	2
	Über bestimmte Integrale*[x]	2
Priv. Doz. Ed. Weyr	Über Flächen zweiter und dritter Ordnung (Fortsetzung)*[x]	2
Priv. Doz. A. Puchta	Zahlenlotterie*	2
	Functionen einen complexen Variablen*	2
K. k. Astronom Prof. C. Hornstein	Analytische Mechanik in Anwendung auf Astronomie (Fortsetzung)*	1
	Geographische Ortsbestimmung; Theorie der Kartenprojektion (Publice)	1
III. Naturhistorische Wissenschaften		
K. k. Regierungsrath Prof. E. Mach	Experimentalphysik (Optik)*	5 (dtto)
	Theoretische Ergänzungen zur Experimentalphysik (Publice)	1 (dtto)
Prof. F. Lippich	Theoretische Mechanik, insbesondere Dynamik*	3 (Wed, Th, Fri)
	Theorie der Bewegung der Flüssigkeiten*	2 (Th, Fri)
Priv. Doz. A. Seydler	Einleitung in die theoretishe Physik, Fortsetzung (Theorie des Potentials, die Lehre von Magnetismus und von der Electricität)*[x]	3 (Mo, Tu, Sat)
Priv. Doz. K. Domalíp	Übungen in der Experimentalphysik*[x]	2, PhI
IV. Wissenschaftliche Seminäre; 2. Mathematisches Seminar [the same as in the winter semester]		

Table 1: Lectures on Mathematics and Physics as announced at the Faculty of Philosophy of Prague University in academic year 1879/80 (the year of E. Mach's first Rectorship) Symbols: * registration to the lecture/seminar was associated with payment of a minimum fee (but there was a possibility to apply for its partial or entire waive), [x] the title of the lecture was announced both in Czech and German.

For students aspiring to become secondary school physics teachers, Mach's lectures were of course a part of broader mathematics-physics classes. Some of Mach's Prague students took part in their organization soon. Thus, in the 1879/80 academic year, when E. Mach held (for the first time) the position of Rector at Prague University, private lecturer K. Domalíp took over (for the first time) a part of the experimental physics classes. He lectured in Czech (as Prague University had become utraquist by that time), (Table 1).

Mach lectured in German; he was, however, able to communicate with his students in Czech. His lessons took place at the Physics Institute. The lectures and seminars were distributed throughout the week in 1 or 1.5 hour units. Registration was (with the exception of free public colleges) associated with the payment of a minimum fee (with the possibility to apply for its partial or entire waiver). A number of Mach's students obtained (thanks to his recommendation) various stipends or other forms of aid. For example, in 1870–1872, the following note was added to information about the Physics Institute in the *Personalstand* yearbooks of Prague University: „*Drei Stipendien von je 100 fl. jährlich*."

Vincenz Strouhal (1850–1922)



Vladimír Novák (1869–1944)

The atmosphere of Mach's lectures can be illustrated also by the memories of Vladimír Novák (1869-1944). He registered for Mach's two-semester Experimental Physics at the German University as an external student in the 1890/91 academic year. It was at the end of his regular studies at the Czech University. At that time he already wor-

ked as an assistant at the Physics Institute of the Czech University headed by professor Čeněk (Vincenc) Strouhal (who had once also been Mach's student). In his memoirs written in the 1930s while still a Physics Professor of many years at the Czech Technical University in Brno, V. Novák says [6]: „*In the last year of the university quadrennial, I attended the lectures of Professor E. Mach as an external student* [...]. *I attended the lectures together with Boh*[umil] *Mašek, and we used to arrive so early that we always had a place on the front bench. Mach soon took notice of us and because we had no reason to rush off after the lecture as the other students (medical students) did, we could examine the instruments and often observe the experiments that Mach used to show after his lecture. Many of Mach's experiments, namely from mechanics and optics, were original and very educational. The clean copies of Mach's lectures, which I drew up immediately after, while they were still fresh in my memory, remain a valuable memento of my university studies.* [They have not survived in V.N.'s estate. E.T.] *Mach's disquisitions, which were preceded by a historical introduction supplemented by appropriate philosophical commentary, were original. They pointed to the frailty and inconsistency of basic physics concepts according to historical development, namely experimental concepts, and were a testimony to the great pedagogical talent of the lecturer.* [...] *Mach accompanied his lectures with beautiful experiments, which he performed himself. At his service was his ‚mechanic' Mr Hájek, who only moved the items from one place to another or maintained order among the students. Mach adjusted many of the experiments for subjective observation, where the observers had to exchange places. These were often the best experiments, which he left, until after the hall emptied, for the few most science-hungry. During the experiments, we admired his dexterity and speed and how he was able to easily help himself in the case of improvisation. Naturally, he had for his optics experiments instruments that were very sophisticated for the time and numerous crystalline chemicals; therefore, certain phenomena, such as Heiding's bands, anomalous dispersion of fuchsine, conical and cylindrical refraction etc., we were able to see demonstrated in exemplary manner.* [...] *when we* [...] *complemented something in our own fashion, Mach spoke to us in Czech.*"

A significant decrease of the number of philosophy students signed up for Mach's lectures, occurred at the onset of the 1880s, before the separation of Prague University into two independent universities, the Czech and the German ones, according to the tutorial languages. Contributing to this decrease was probably the „competition" from lectures offered concurrently in Czech. For example, in the 1880/81 academic year, only 11 philosophers (4 Czech, 6 German, 1 Serbian) signed up for Mach's lectures in the winter semester and 9 (2 Czech and 7 German) in the summer semester. Everyone from the winter semester signed up for Mach's *Experimental Physik I. Theil* (5 lessons per week). The course *Experimentální fyzika* (Experimental Physics, in Czech) offered in this semester by private lecturer K. Domalíp (2 hours per week) had 8 philosophy students (of course of Czech nationality) signed up for it (concurrently or alternatively). Similarly in the summer semester, 5 philosophers (3 German and 2 Czech) signed up for Mach's

Praktische Übungen (2 lessons per week) and 9 students (of Czech nationality) signed up for seminars with a similar Czech title (*Cvičení v experimentální fysice*, 2 hours) offered by K. Domalíp.

The number of philosophers signed up for Mach's lectures and seminars, fluctuating at around ten, corresponds even to the situation after the division of Prague University in 1882, when E. Mach transferred (together with his Physics Institute) to the German University. From the end of the 1880s, also E. Mach's lecturing activity was clearly declining, and he left a part of the routine basic lessons (physics for pharmacists and practica) gradually (and probably with relief) to his assistants Ottokar Tumlíř (transcribed also as Tumlirz) and after him to Gustav Jaumann.

Even after the separation of Prague University, we can find among the regular students of the German University individuals claiming Czech nationality. We consider a more interesting phenomenon, however, to be the case of regular students of the Czech University who signed up as irregular students there, with an interest in selected lectures and seminars. In addition to the mentioned V. Novák and his classmate, then astronomer and very active secondary school teacher Bohuslav Mašek (1868–1955), we can mention Václav Felix (1873–1933). In the 1890/91–1893/94 academic years he studied mathematics and physics as a regular student of the Czech University. In 1891/92–1894/95 (with the exception of the summer semester of 1893) he signed up also as an irregular student of the German University, first for the mathematics lectures of Professor H. Durège and in the 1894/95 academic year for E. Mach's lectures in experimental physics (for which he had to pay tuition of 5 florin and 25 kreuzer each semester). In 1895 he attained at the Czech University the ability to teach mathematics and physics at higher secondary schools and a doctorate in philosophy. His later academic career was associated with the Czech Technical University in Prague, where in 1900 he became a Professor of Physics. In the summer semester of 1895, just before Mach's departure from Prague, another regular student of the Czech University signed up as an irregular student at the German University: František Nachtikal (1874–1939). He signed up first for lectures on mathematics (G. Pick, K. Bobek) and astronomy (L. Weinek), but not for the lectures of E. Mach, which he apparently planned to attend in the next semester. This opportunity, however, was not given to him. He himself also became a Professor of Physics at the Technical University, first at the Czech Technical University in Brno, then in Prague. The impulse to attend Mach's or other mathematics-physics lectures at the German University was most likely given to the most curious students of the Czech University by their Czech professors of physics Č. Strouhal and F. Koláček (see also below).

A keen student of E. Mach was Beno Urbach (born 1869, of German nationality). He studied medicine first and then continued with the study of philosophy. He signed up for Mach's two semester *Experimental Physik* in the 1892/93 and 1893/94 academic years as an irregular student and in 1894/95 again, at that time already as a regular student of the Faculty of Philosophy of the German University. He also signed up for

physics seminars (and other lectures) headed at that time by Professor G. Jaumann. By the way, in the 1920s, Beno Urbach joined the lively discussion on the theory of relativity tabled in the Prague German Union of Natural History „Lotos". He was one of those who opposed critics of the theory of relativity from the camp of Prague German philosopher O. Kraus. [7]

It is not without interest that in the 1891/92 academic year E. Mach's son Heinrich (1874–1894) became his student. Heinrich studied pharmacy at Prague German University. He was the only pharmacist in his class to sign up for both parts of Experimental Physik lectured by his father. Shortly after completing his studies he committed suicide, which was for E. Mach and his family surely one of the most difficult moments of their stay in Prague. Even his oldest son Ludwig (1868–1951), who studied medicine, probably attended his father's lectures of physics for medical students. In addition to that, he helped his father at the Physics Institute and later even become the co-author of some of E. Mach's scientific works.

Doctors of Philosophy

E. Mach brought not only one of his students to scientific work and other academic careers. A list of 12 doctorate theses of Prague/Prague German University presented following the new doctoral viva voce rules of 1872, and associated with an opinion of Professor E. Mach have already been published [2, 3, 4].

In the case of those twelve doctorate theses, E. Mach was appointed (by the management of the Faculty of Philosophy) as one of two professors responsible for the area of the thesis topics or for an area which was close to them. E. Mach figured as the main reviewer of nine of them (that can be regarded as carried out under his supervision) and Professor F. Lippich as the second reviewer. The topic of the rest was astronomy (spectroscopy) or chemistry (including the thesis by B. Brauner presented in 1880). E. Mach covered for the second reviewer for their topics.

Mach's review given on the doctoral thesis of his student and assistant Joseph Wanka (born 1867 in Prague, who applied for the title of Doctor of Philosophy at Prague German University in 1893) may serve as an example of the reviews [27]:

„Referat über die Dissertation des Herrn J. Wanka.

Herr Wanka hat die ‚Condensationschwingungen', auf deren Beobachtung ihn ein Zufall geführt hatte, in mannigfaltigen geschickt und elegant angestellten Experimenten anfolgt. Die beobachteten Vorgänge werden in der vorliegenden Abhandlung qualitativ aus den Grundsätzen der mechanischen Wärmetheorie erklärt. Von besonderem Interesse sind die S 23 u. ff. beschriebenen Versuche mit verschiedenen Flüssigkeiten, und der Hinweis auf den Umstand, dass das verschiedene Verhalten derselben mit dem Zeichen der specifischen Wärme der gesättigten Dämpfe derselben zusammenhängt.

Sowohl die Experimente als auch die theoretischen Beobachtungen lassen die wissenschaftliche Selbständigkeit des Verfassers erkennen, und Referent mußte demnach die

Dissertation als den gesetzlichen Anforderungen vollkommen entsprechend bezeichnen.
Prag 7 Febr 1894 *E Mach*
Die Arbeit ist rein physikalisch und der entsprechende Referent ist demnach Herr Prof. Lippich."

The final university report card (*Abgangs-Zeugniss*) of J. Wanka provides an overall view of his university studies in Prague in 1886/87–1890/91. The report was attached to his application for the title of Doctor of Philosophy at Prague German University in 1893. His application was sent off from Fiume (Rijeka) where he had been appointed a substitute teacher at the Navy Academy. His university „profile" can be compared with the „profile" of another of Mach's Prague doctors of philosophy, Johann Luggin (born 1863 in Klagenfurt), who studied at the universities in Vienna and Strasbourg before his arrival in Prague in 1885. He presented two papers (*Eine einfache Methode zur Vergleichung magnetischer Felder, Versuche und Bemerkungen über den galvanischen Lichtbogen*) published in the proceedings of the Vienna Academy of Sciences in 1887 as his doctoral thesis at Prague German University. Both these studies were carried out under the supervision of E. Mach (see Table 2).

The total number of doctorate theses on mathematics and physics presented at Prague University was not high at the time. In the period of 1882–1894, a total of 67 doctorate theses were presented at the Faculty of Philosophy of Prague German University, three of which related to mathematics and six to physics (4 drawn up under Mach's supervision).

New Teachers of Physics

As a new teaching staff for (experimental) physics, M. Neumann (1846–1873) in 1871, and Č. Dvořák (1848–1922) in 1872, were appointed private lecturers at Prague University. But it was not for long. Neumann died in 1873. Apart from the already mentioned physics for medical students, he announced successively the courses entitled *Heat and Equilibrium of Gases and Liquids* (2 l, in Czech), *Physikalische Technik* (1 l), and *On Radiative Heat* (2 l, in Czech). Dvořák's teaching activity at Prague University was a bit longer. His lectures focused on historical topics: *Über die Optik des Huyghens und Newton* (1 l), *Die Physik des Stevinus und Galilei* (1 l), *Die Entwicklung der Mechanik im Zeitalter des Newton* (1 l). In 1875, he left his homeland for Croatia, where he became a professor of physics at the university in Agram (Zagreb). He spent the rest of his life there. V. Dvořák became well-known for his experiments on acoustic forces. He constructed (independently from Rayleigh) an acoustic radiometer. Both Neumann and Dvořák had been Mach's students and assistants.

The position of private lecturer (*Privat Dozent*) authorized the person to lecturing at the university on a specified subject but it was not connected with a salary. The remuneration for such lectures depended on the fees collected from the students signed up for them.

Luggin Johann (b. 1863 Klagenfurt)

University, Vienna

1881/82:	**WS**	Lang:	Experimentalphysik, 5
		Lieben:	Allgemeine Chemie, 5
		Zimermann:	Geschichte der Philosophie, 3
	SS	Königsberger:	Algebra, 6
		Weyr:	Geometrie, 5
		Stefan:	Optik, 4
1882/83:	**WS**	Königsberger:	Differentialrechnung, 3
			Mathematisches Unterseminar, 1
		Weyr:	Geometrie, 5
		Weyr:	Mathematische Untersuchungen, 1
		Stefan:	Mechanik-Experimentieren, 4-6
		Hann:	Meteorologie, 2
	SS	Königsberger:	Differentialrechnungen; 6
			Differentialgleichungen, 1
			Mathematisches Seminar, 1
		Stefan:	Akustik u. Theorie der Wärme, 4
		Loschmidt:	Ergebnisse der physikalischen Forschung, 2
			Physikalische Chemie, 3
		Zimermann:	Logik, (?)
1883/4:	**WS**	Königsberger:	Functionentheorie, 6
			Übungen im mathematischen Seminar, 2
		Weyr:	Geometrie, 4
		Stefan:	Magnetismus - physik. Experimentieren, 4/6
		Exner:	Elektricität, 2
		Haubner:	Wärmeleitung, 2

University, Strasbourg

1884:	**SS**	Roye:	Synthetische Geometrie, -
			Mathematische Theorie der Elasticität fester Körper, -
		Christoffel:	Anwendung der complexen Integration, (?)
		Kohlrausch:	Electrostatik u. Magnetismus, -
			Anwendung der Electricität,-
		Kundt:	Praktische Übungen, (?)
1884/85:	**WS**	Roye:	Geometrie, Potentialtheorie, -
		Kundt:	Experimentalphysik, -
			Übungen im Laboratorium, -
		Bohn:	Wärmetheorie, -

German University, Prague

1885:	**SS**	Mach:	Experimentalphysik, 5
			Experimentalübungen, -
		Tumlirz:	Theorie des Lichtes, 2
		Lippich:	Mathematische Physik, 2
1885/86:	**WS**	Pick:	Differentialgleichungen, 2
		Mach:	Experimentalphysik, 5
			Experimentalübungen, -
		Tumlirz:	Mechanik, 2
		Lippich:	Magnetismus, 2
	SS	Marty:	Logik, 4
		Jodl:	Psychologie, 5

Table 2: a) Lectures attended by Johann Luggin during his studies at the Universities in Vienna, Strasbourg and Prague in 1881/82–1885/86 (as documented at his application for the degree of Doctor of Philosophy at Prague German University, dated 23 July 1887) [26].

Wanka Joseph (b. 1867 Prag)
German University, Prague

1886/87:	**WS**	Durège:	Analytische Geometrie der Ebene, 5
		Mach:	Experimentalphysik, 5
	SS	Durège:	Über algebraische Curven, 2
		Mach:	Experimentalphysik, 5
		Puchta:	Differential- und Integralrechnung, 3
1887/88:	**WS**	Durège:	Differential- und Integralrechnung, 3
			Analytische Geometrie des Raumes, 2
		Mach:	Experimentalphysik, 5
		Tumlirz:	Physikalisches Praktikum, 2
			Wellenlehre für Anfänger, 2
		Weinek:	Bahnberechnung der Planeten, 1
	SS	Durège:	Differential- und Integralrechnung, 3
			Curven im Raume u. krümme Flächen, 2
		Biermann:	Theorie der Function realen Variablen, 2
		Pick:	Elemente der Wariationsrechnung, 2
		Mach:	Experimentalphysik, 5
		Tumlirz:	Praktisch-physikalische Übungen, 2
			Geschichte der Physik, 1
		Weinek:	Passagen-Instrument im Meridian, 3
			Praktisches Beobachten, 2
1888/89:	**WS**	Durège:	Analytische Geometrie der Ebene, 3
			Über Differentialgleichungen, 2
		Pick:	Bestimmte Integrale, 2
		Biermann:	Elemente der projekt. Geometrie der Ebene, 2
		Mach:	Anleitung zu selbständigen Arbeiten, -
		Lippich:	Theoretische Mechanik, 3
			Theorie der dioptrischen Instrumente, 2
		Tumlirz:	Theorie der Flüssigkeitsreibung, 1
		Weinek:	Kometen-Bahnbestimmung, 3
		Marty:	Psychologie, 5
	SS	Durège:	Elemente der Functionentheorie, 3
			Theorie der Gleichungen, 2
		Biermann:	Theorie der Curven und krümmen Flächen, 2
		Pick:	Elemente der Zahlentheorie, 3
		Lippich:	Theorie der Wärmeleitung, 2
			Theoretische Mechanik, 3
		Tumlirz:	Entziehung eines homogenen Ellipsoides, 1
		Weinek:	Theorie und Praxis des Aequatoriel, 3
		Marty:	Psychologie, 4
		Willmann:	Wesen und Geschichte des Gymnasiums, 2
			Methodik, 1
		Schultz:	Geschichte der berühmten Maler, 2
			Kunstgeschichtliche Übungen, 1
1889/90:	**WS**	Pick:	Elliptische Integrale und Functionen, 3
		Durège:	Mathematisches Seminar, 2
		Lippich:	Mathematisches Seminar, 2
		Lippich:	Mechanische Wärmetheorie, 3
			Theorie der Elasticität fester Körper, 2
		Tumlirz:	Wärmelehre, 2
		Weinek:	Sphärische Astronomie, 3
		Maly:	Anorganische Chemie, 5
		Willmann:	Geschichte der neueren Philosophie, 3
		Schultz:	Geschichte der deutschen Kunst, 2
	SS	Pick:	Algebraische Analysis, 3
			Elliptische Functionen, 2
		Durège:	Mathematisches Seminar, 2
		Lippich:	Mathematisches Seminar, 2
		Lippich:	Theoretische Optik, 3
			Akustik, 2
		Tumlirz:	Elektromagnetische Theorie des Lichtes, 3
		Weinek:	Einleitung in die Theorie der Instrumente, 3
			Übungen im astronomischen Beobachten, 2
			Geograph. Ortsbestimmung auf Reisen, 1
		Maly:	Analytisch-chemische Übungen, 5
		Willmann:	Gymnasial Pädagogik, 3
1890/91:	**WS**	-	
	SS	Sauer:	Goethe und Schiller 1795-1805, 3

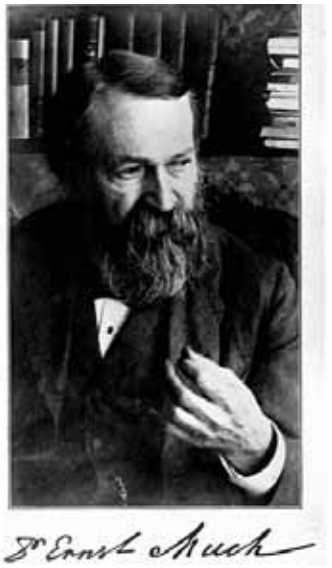
Table 2: b) Lectures attended by Joseph Wanka during his studies at Prague German University in 1886/87–1890/91 (as documented at his application for the degree of Doctor of Philosophy, dated 23 August 1893) [27].

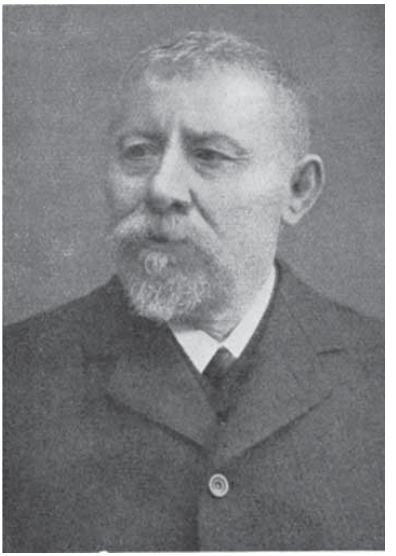
In 1877, with the support of E. Mach, another of his former students, K. Domalíp (1846-1909) was appointed a private lecturer for experimental physics at Prague University. Domalíp, after completing his university studies, was the first assistant to K. A. Waltenhofen at the German Technical University in Prague. He gave his lectures in Czech at Prague University and in 1882, he naturally transferred to the newly established Czech University. In 1884, he gave up the university position in favour of a position of a private lecturer of electro-technology at the Czech Technical University in Prague, in which field he became a professor in 1893.

Vincenz Dvořák (1848–1922)

Karel Domalíp (1846–1909)

For physics (theoretical physics), A. Seydler (1849–1891) was appointed private lecturer at Prague University in 1872. He also belongs to Mach's Prague students. He started his professional career as an assistant/adjunct of the Astronomical Observatory of Prague University. Even he transferred to the Czech University in 1882, where he was appointed a Associate Professor of Mathematical Physics and in 1885 full-time Professor of Theoretical Astronomy and Mathematical Physics. The division of the previously joint chair of mathematical physics and astronomy at Prague Czech University took place until after his death. In 1892, Gustav Gruss (1854–1922) became a Professor of Astronomy. Of course, he also attended Mach's university lectures in experimental physics. In 1891, František Koláček (1851–1913), the first of E. Mach's Prague doctors of philosophy (in the sense mentioned), was appointed a Professor of Mathematical Physics. His thesis dealt with electromagnetic theory of the dispersion of light. The preserved eight-page letter written by E. Mach to F. Koláček dated 18 April 1877 demonstrates E. Mach's vivid interest in this topic and his supervision (see the Supplements). Until his appointment as a Professor of Mathematical Physics at Prague University, F. Koláček, somewhat paradoxically with regard to his physics erudition, was a secondary school teacher in Brno for almost 20 years (in the years 1882–1884 shortly also as a private lecturer of

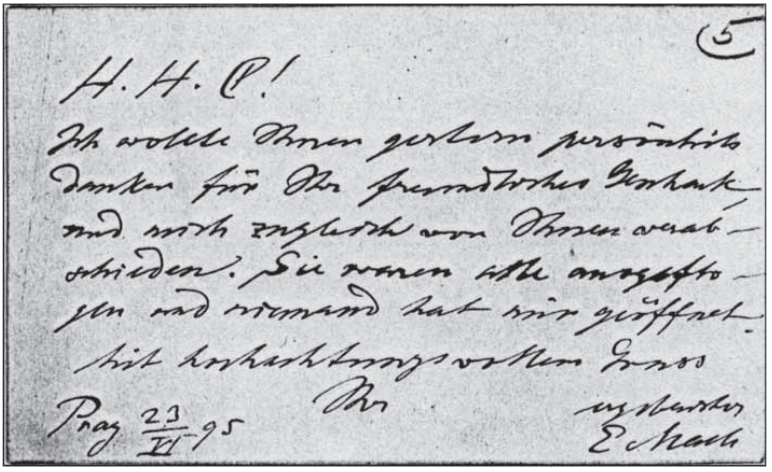




Ernst Mach (left) and his former Czech student František Koláček (1851–1913) (right).

mathematical physics at Brno Technical University but he gave up this position for the sake of his responsibilities as a secondary school teacher). Nevertheless, a bibliography of his work compiled up to 1887 includes 23 items. E. Mach lobbied for Koláček's appointment as a Professor at the newly founded Czech University in 1882, but without success. In a letter dated 31 March 1882 regarding this issue, he wrote to Koláček [8]: *„Verehrter Herr Professor! Mehrmals hat sich mir ungesucht die Gelegenheit dargeboten, als von d. Besetzung d. Professur für Physik an d. neuen Universität die Rede war, auf Sie hinzuweisen. Da persönliche Rücksichten und Rücksichten der Billigkeit, zum Theil solche, welche man anerkennen muss, ins Spiel kommen werden, so ist es zwar nicht wahrscheinlich, dass man Ihnen den Vorzug geben wird – denn es handelt sich ja um die Befriedigung der Leute in Prag –, es kann Ihnen aber vielleicht doch nützlich sein, von der Sache zu wissen. Dies ist der Grund, weshalb ich Ihnen hievon Mittheilung mache. Mit der Versicherung, dass ich an Ihren Schicksalen aufrichtigen Antheil nehme hochachtungsvoll grüssend Ihr ergebenster E Mach.“* The amicable relationship between Koláček and Mach is supported even by a Mach's calling card that apparently relates to his departure from Prague and documents his bidding farewell to his friends (see also Supplements).

Čeněk (Vincenz) Strouhal (1850–1922) was appointed a Professor of Experimental Physics at Prague Czech University in 1882. His scientific career was also influenced



Reverse side of E. Mach's business card with a note for F. Koláček (dated Prague, 23 June 1895).

significantly by E. Mach when, after his graduation, Mach recommended him as an assistant to Friedrich Kohlrausch at the University in Würzburg. Strouhal was active there in the years 1875–1882. During this period, in 1878, he underwent conferment through work on so-called „friction tones" (in which he defined and experimentally very precisely determined the constant that is called „Strouhal number" today). In Würzburg, he took part in organizing practical student seminars and physics lectures, and assisted with the building of a modern physics institute. All this experience was used by him in building the foundation of physics studies at the Czech University in Prague, which, in 1882, started only with a very modest, provisional fit out with respect to the experimental physics institute and its teaching aids.

During the process of occupying the position of a Professor of Experimental Physics at the Czech University, the job was also offered (by Czech academic circles) to V. Dvořák who was still in Agram. He, however, refused the offer. Firstly, he had already settled in his new workplace; secondly, he was aware of the difficult tasks that needed to be taken on with respect to the new professorial position. His reasons, which also expressed a critical opinion of the physics lessons at that time at Prague University, were shown to be an entirely realistic assessment of the situation. In his letter to the Professor of Mathematics F. J. Studnička dated 23 February 1882, he summarized his concerns as follows (his level of Czech already reflected the many years that he was away from his homeland) [9]:

„If I were a Professor of Mathematics or of some other science, I would apply for a professorship in Prague with pleasure. But the situation with physics is different.

Let us have a look at what is now required from a professor of physics:

1) Giving lectures and even experimental lectures, which take up an enormous amount of time if they are to be performed properly.

2) Holding practical tutorials with students, and even putting together a physics seminar. Already for this it is necessary to have the entire strength of one person who is already adapted to this role, provided one is to work here at an advanced level, as is the case in the physics laboratories of some German universities.

3) Educating and developing the personnel for the university. This point is not the same as point two, it again requires special work.

4) Working independently in science. Experimental research requires much, very much time.

5) Lecturing to philosophers as well as to medical students and pharmacists. Because of this, in Prague, physics in its entirety is lectured in two instead of four semesters. This without doubt results in the lectures not teaching anything to anyone, neither to the philosophers nor to the others.

[...] *equipping a new cabinet would take up 3–4 years of my time, provided funds would be made available for this (which I doubt). What the cabinet rooms will be like is entirely unknown; this cannot be unimportant to a professor of physics who will truly spend his entire life in these rooms.* [...]"Another reason for Dvořák's refusal of the offer was the then higher cost of living in Prague than in Zagreb.

E. Mach, as the only professor of experimental physics at Prague University at that time, naturally participated in all of the mentioned appointments (except Č. Strouhal's one in Würzburg) and supported them. In 1877, he drew up an opinion also on the conferment work on musical acoustics entitled *Die Lehre von den musikalischen Klängen als Grundlegung einer aesthetischen Harmonielehre* of Otokar Hostinský (1847–1910), who later became one of the leading representatives of Czech aesthetics, history of arts and musicology. [2]

E. Mach took a very critical stance to the conferment, scientific abilities and behaviour of Štěpán Doubrava, as is demonstrated by E. Mach's correspondence with A. Seydler from 1882. Š. Doubrava (1857–1898) obtained his philosophy degree from Prague University in 1881. Until the division of the university, he worked in Mach's physics institute. In 1882 he became the assistant to Professor Č. Strouhal at the Czech University and immediately at the end of this year requested conferment in practical physics. For his conferment work, he presented a small document *O elektřině* (*Über die Electricität*, Prague 1882), published in both Czech and German. Although A. Seydler made a commendable report on this paper in domestic and foreign journals, E. Mach considered it necessary to distance himself from Doubrava's ideas and sent the following statement to the *Annalen der Physik* [10]: *„Ich sehe mich veranlasst zu erklären, dass die von H. Doubrava in seiner kürzlich erschienenen Schrift ‚Über Elektricität' dargelegten Ansichten mit den meinigen nicht zu identificieren sind."* Mach, who was deeply philosophical, would have criticized in particular the conceptual and ideological structure

of the Doubrava's work. Despite the critical evaluation given by E. Mach, Doubrava was granted conferment at the Czech University in 1883. In the evaluation of the committee that was created to assess his request and was composed of professors V. Strouhal, A. Seydler and F. J. Studnička, Mach's admonitions were considered (indirectly) with the following words: „[...] *if then* [Doubrava] *was led here and there to theoretical opinions that will generally not be recognized as correct and which he will himself later change and correct, one must above all appreciate and recognize the independence and efforts of his research, and because one cannot deny the scientific value of the experimental part of his work, the committee thus deems the presented conferment work as satisfactory."* Doubrava lectured at Prague Czech University as a private lecturer until the end of the 1886/87 academic year. At the end of 1888 he decided to give up lecturing and devoted himself fully to being an entrepreneur and inventor in the field of electrical engineering. [11]

At the German University, it was Ottokar Tumlíř (1856–1928), who was appointed private lecturer for physics in 1882, who first helped Professor E. Mach with arranging lectures in experimental physics. He studied at Prague University in the years 1874/75–1877/78. From 1878 he was an auxiliary and from 1880 a full-time assistant in Mach's physics institute. His first publication, including his doctorate thesis in 1879, dealt with the expansion of sound and light waves. He, however, became more and more interested in theoretical physics, which preference was reflected even in his university lectures. Before the beginning of the 1890/91 academic year, with regard to the repeated lack of success in his efforts to be named Professor at Prague German University, he transferred to Vienna, where he accepted a position at a private secondary school. At the same time, he put in a request for the transfer of his Prague conferment for physics to Vienna university, to which the Ministry of Culture and Education gave its approval (based on the recommendation of the committee, a member of which was, among others, physicist J. Loschmidt). Tumlíř's bibliography of scientific works compiled on this occasion included 24 items published up to 1890, among them two monographies: *Elektromagnetische Theorie des Lichtes* (Leipzig 1883, 158 p., which he dedicated in the foreword to Professor E. Mach, *„seinem hochverehrten Lehrer und Gönner"*) and *Das Potential und seine Anwendung zu der Erklärung der elektrischen Erscheinungen* (Wien 1884, 302 p.). In the proposal for lectures, which he aimed to perform at Vienna University, he stated the following program for 10 semesters: 1. *Potentialfunction und Potential* (2 hours per week) 2. *Elektrodynamik und Induktion elektrischer Ströme* (2 hours); 3. *Elektromagnetische Lichttheorie*, (4); 4. *Elasticität fester Körper* (2); 5. *Undulationstheorie des Lichtes* (4); 6. *Dioptrik* (1); 7 *Hydrodynamik* (3); 8. *Flüßigkeitsreibung* (2); 9. *Wärmestrahlung* (2); 10. *Mechanische Wärmetheorie* (3). To this he added the clause: *„Die meisten der hier angeführten Vorlesungen wurden von den Bittsteller an der k.k. deutschen Universität in Prag zum wiederholten Male gelesen."* In 1891, O. Tumlíř was appointed a Professor of Physics at the University in Černivci (Czernowitz). His last place of work was University of Innsbruck, where he worked as a Professor of Theoretical

Physics in 1905–1926. In the history of physics, he is also quoted in connection with his work *Ein neuer physikalischer Beweis der Axendrehung der Erde* from 1908. [12]

O. Tumlíř's successor to the position of assistant to E. Mach in the physics institute in Prague was Gustav Jaumann (1863–1924), who had also held the position of auxiliary assistant for a number of years before. He had originally studied chemistry, first at the Technical University in Prague and then in Vienna, after which he transferred to the university in Prague. He mentioned in his curriculum vitae, which he had attached to his request for conferment in physics and physical chemistry at Prague German University in 1890 [13]: *„Unter dem Eindruck der ersten Universitätsvorlesungen, welchen derselbe [G. J.] in 1883/84 als ausserordentlicher Hörer beiwohnte, wandte er sich dem Studium der Experimentalphysik zu, erhielt 1885 die Assistentenstelle am physikalischen Institute, welche er seither innehat und vollendete 1886 seine Studien."* G. Jaumann also became Mach's co-author of a secondary school physics textbook entitled *Grundriss der Naturlehre für die oberen Klassen der Mittelschulen* (first edition Prague 1890, 335 pages + 429 illustrations in the Realschulen edition; 372 pages + 431 illustrations in the *Gymnasien* edition). G. Jaumann was the author of texts on electricity and magnetism (in the edition for grammar schools also on chemical processes) and supplements on astronomical and meteorological phenomena. He took the position of Mach's original co-author, Dr. Johann Odstrčil, a professor at the German state grammar school in Děčin, who had died suddenly. In 1893, G. Jaumann was appointed a Associate Professor of Physical Chemistry at the German University in Prague. In 1901, he left for Brno to take the position of a full-time professor at the German Technical University there. In terms of scientific work, he devoted himself firstly to the issues of scientific instruments. For example, he proposed an improvement to W. Thomson's *Schutzringelektrometer*. Later, his subject of interest became the substance and nature of cathode rays. This led him to the formulation of a „longitudinal theory of light". He also contemplated establishing physics and chemistry on the same foundation of a small number of constants. Both theories brought about discussion and criticism.

The appointment of G. Jaumann an Associate Professor was discussed already in the autumn of 1892, i.e. only two years after his conferment. The committee that was assigned to consider the proposal was composed of E. Mach, F. Lippich, the mathematician G. Pick (who in 1880–1883 also worked as an assistant in Mach's physics institute) and chemist G. Goldschmiedt. E. Mach, as the speaker for the committee, in the paper dated 9 November 1892, reasoned the unusually early proposal to have the private lecturer G. Jaumann made associate professor by mentioning his many years of activity in science and his graduation and conferment at a more advanced age. He completed the picture of the candidate with the words [13]: *„Der unterzeichnete Berichterstatter* [E. Mach] *pflegt in seinen Vorlesungen, nachdem die herkömmliche Auffassung einer Sache erledigt ist, auf andere mögliche Auffassungen hinzuweisen, was zuweilen bei einem lebhafteren Auditorium zu Ausführungen und Diskussionen von Seiten der Zuhörer, gewöhnlich in Form von anonymen Briefen an den Berichterstatter Anlass gibt. Meist*

hat der Inhalt dieser Briefe wenig zu bedeuten. Im Wintersemester 1883 aber erhielt der Berichterstatter bei einem ähnlichen Anlass ein anonymes Schreiben, dessen Inhalt soweit über das Niveau der gewöhnlichen Studentenphilosophie stand, dass er den lebhaften Wunsch fühlte, die Bekanntschaft des Schreibers zu machen, und dass er diese durch einen Anschlag im Hörsaale herbeiführte. Der Schreiber des Briefes war Jaumann, welcher von da an mit dem Institute in Verbindung blieb.

Von dem Augenblick an, als Jaumann ins Institut eingetreten war, hat er nur der wissenschaftlichen Arbeit gelebt, so zwar, daß der Berichterstatter zur Vermeidung von Anordnungen sich genöthigt sah, eine feste Stunde für den Schluss des Institutes am Abend festzusetzen, welche Maßregel sich vorher als ganz unnöthig gezeigt hatte. War Jaumann von allen Jungen Physikern, mit welchen der Berichterstatter auf seiner lehramtlichen Laufbahn in Berührung gekommen ist, am leichtesten anzuregen, so war er trotzdem auch von allen der selbständigste, der sich in origineller Weise seine Ziele setzte und dieselben in energischer ausdauernder Arbeit verfolgte. Die Ergebnisse seiner Arbeit wußte Jaumann gleich das erstemal so correct und sorgfältig stilisirt niederzuschreiben, daß nichts daran auszusetzen war. Hiebei zeigte er sich stets auch darin als eine vornehme Natur, daß er auch die geringste von anderer Seite erhaltene Anregung nicht verschwing."

The flattering words expressed by E. Mach about G. Jaumann in 1892 contrast the passages in Mach's correspondence from 1894 [4]: *„I wish in the case of my death, that the Institute not be given to Jaumann, at least not immediately. [...] Jaumann has for the last ten years, so to say, worked as a guest, that is, for himself and for that drawn a salary. During the first few years I requested very little from him as an assistant, and then nothing at all. On the contrary, I was continually having to defend myself against his tendency toward extravagant behaviour and disorder. The assistant's work: Preparing for the lecture, putting back the apparatus, ordering cost-free new equipment, organizing and administering material, and handling related correspondence, has all been done during the last four years by my son Ludwig, solely out of concern to help me. He has with great effort by using the means available to Jaumann brought everything into tiptop order."*

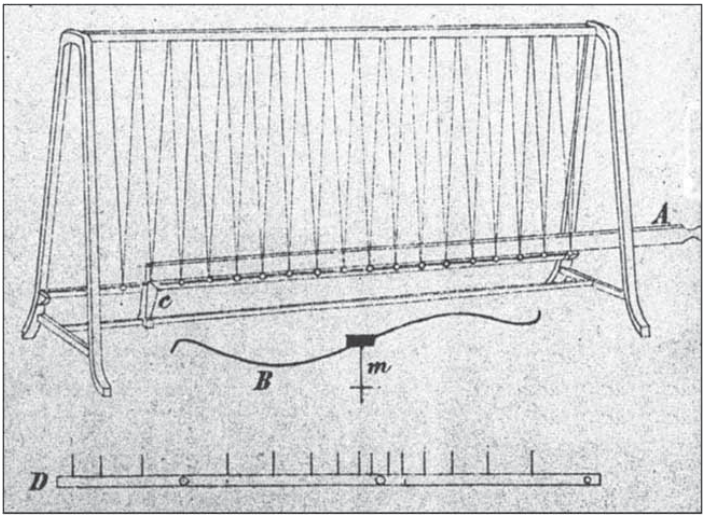
Despite Mach's accommodating and affable approach to his students, be they of Czech or German nationality, certain conflict had to have arisen – opinion-wise and personally. As an aside, Jaromír Wosyka (transcribed also as Wossyka/Wossika/Wosika)[1], who was also a helper at the physics institute in the mid-1870s, caused E. Mach to have, figuratively speaking, many sleepless nights, when he stole some books from the physics institute. For this Wosyka was fired from the institute. [4]

[1] Own names are described by orthography of contemporary documents and represented frequent variation between Czech name and German transcription.

The Physics Institute

The Physics Institute at Prague University was located at the time of E. Mach's arrival in Prague in the main university building, in Prague at Obstmarkt (Ovocný trh) no. 7/562- I. Its premises were cramped. The staff comprised the head, one assistant (PhDr. Anton Grünwald) and an attendant (*Cabinetsdiener*, Josef Zirm).

The Institute moved to that site from Prague, Clementinum, around 1860. It was first called *physikalisches Cabinet*, the designation *physikalisches Institut* was used only later, from about 1881. In 1875, the newly established *Mathematisch-physikalisches Cabinet* headed by Professor F. Lippich gained premises next door (Obstmarkt 5). Its staff comprised the head and one assistant (or at least the position of an assistant).



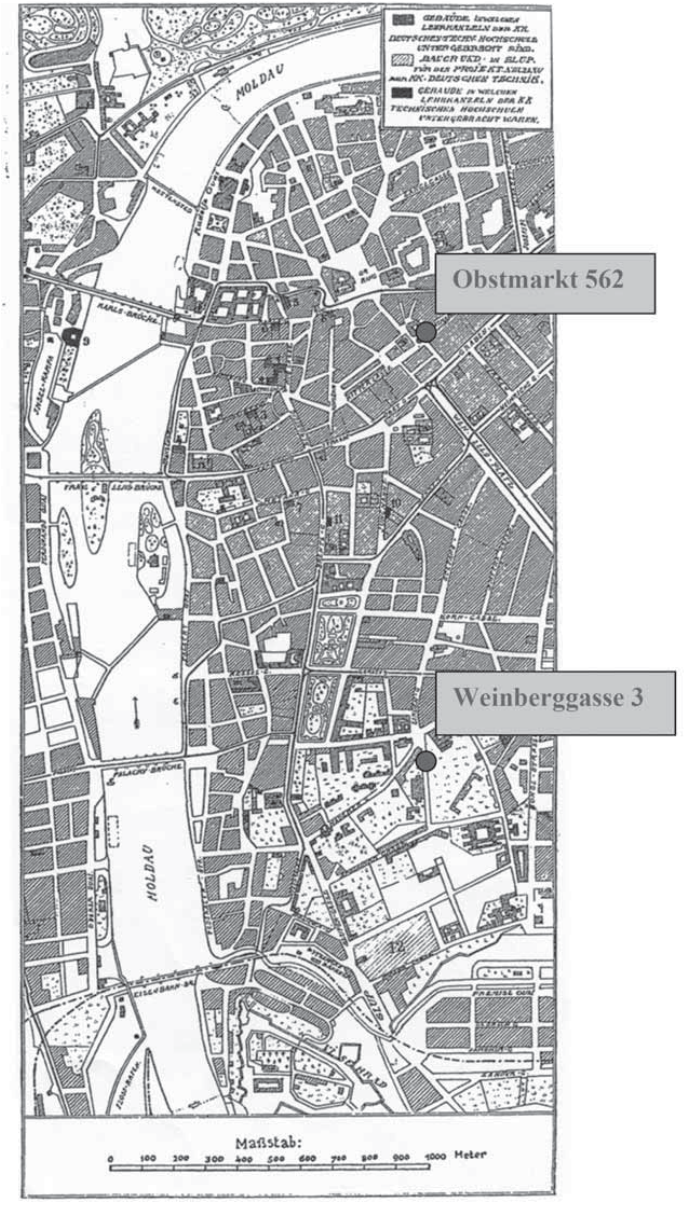
Design of the Mach's Wave Machine (attached to a description of its functioning by M. Neumann in 1870).

After Mach's appointment, a new attendant was hired for the Physics Institute at the end of 1867, and subsequently a proper mechanics workshop was built. The attendant was Franz Hájek (born 1839), a trained carpenter who had just completed eight years of active military service. He was first hired as a temporary employee. The official title of mechanic was allotted to him in 1880. He made a number of physics instruments and teaching aids for the Institute. Some acoustic, optic and electronic instruments *„created in part according to the data provided by professor E. Mach"* were exhibited in 1873 at the world exhibition in Vienna (instruments for demonstration of reflection and refraction of sound, for the study of sound vibrations, for observing sound waves using

a stroboscope, Mach's wave machine, Mach's electroscope and others). In the yearbook of the staff and institutes of Prague University for the 1874/75 academic year, to Hájek's name was added the title *„Inhaber der Weltsausstellungs-Fortschrittsmedaille und der Broncemedaille der Prager Gewerbeausstellung 1874"*. Assistants at the institute (such as M. Neumann) also contributed to the creation of the instruments and teaching aids.

E. Mach appreciated Hájek's work at the institute and he defended him full-heartedly against attacks and anonymous incriminations that Hájek was operating his own business in parallel and had a dangerous affinity to pyrotechnics. An entirely opposite approach was taken by Mach's successor in Prague, professor E. Lecher, who did not intend to tolerate Hájek's private business ventures (being realized in detriment to his services to the institute) and forced him to retire. As Hájek's replacement, Lecher summoned his previous mechanic from the university in Innsbruck, Eugene Hammermüller. [14]

The first residential address of E. Mach (and his family) in Prague seems to be Wassergasse street 642. After a few years, they moved to the upper floor of the building of the Physics Institute. At the end of 1879, the Institute was moved from Obstmarkt to a new building of the natural sciences institutes at Weinberggasse 3 (together with the Mathematics-Physics cabinet of F. Lippich and the Zoological, Mineralogical and Geological Institutes). From E. Mach's correspondence with the Vienna Ministry of Culture and Education regarding reimbursement of the cost associated with the institutes' move (dated of November 1879, and held by Mach as the Rector of the University and at the same time the head of the Physics Institute) we have found out that the Physics Institute's inventory comprised at that time [15]: *„1. circa 1 500 Nummern an Apparaten, darunter viele sehr schwere Stücke, welche besonders transportiert werden müssen und viele sehr gebrechliche [...]; 2. circa 200 Bände Bücher; 3. Möbel und zwar wenigstens 10 grosse Apparatekästen [...] und mehrere Tischen."* The lump sum (requested in October 1879) for the move of the mentioned institutes amounted to a total of 1,480 florins, of which 300 florins were allotted to the Physics Institute and 80 for the Mathematics-Physics Institute. The biggest amount – 500 florins – was demanded by the Zoological Institute. After the move, it was necessary to furnish the new, much larger premises. E. Mach was forced to reduce the original budget associated with this fit out in the amount of 8,727 fl. 20 kr. to 5,579 fl. 90 kr. by the Ministry. His objections that the required reduction would in fact threaten the move were futile. In the original proposal, 13 rooms are mentioned (excluding the flats of assistants and professor). He indicated that the request for fitting out the following rooms could not be reduced: 1 lecture theatre, 1 room serving as a preparatory room for lectures, 1 engine-room (*Motorzimmer*), the workshops and flat of the attendant, and 5 large work rooms. Savings (temporary) he allowed with respect to furnishing the following rooms: 1 room for the professor, 2 work rooms, 2 rooms with the library and the assistant's flat. Through this he arrived at the amount of 5,579 fl. 90 kr., which showed itself to be insufficient in the end. Therefore, in September 1880 he requested an additional 3,000 fl.: *„Da man hierbei fünf Zimmer des neuen Institutes uneingerichtet bleiben mussten, so erlaubt sich der*



Residences of the Physics Institute of Prague (German) University (Obstmakrt 562 up to 1879, then Weinberggasse 3).

ergebenst Unterzeichnete auf die schon in Beilage 1 in Aussicht gestellte Bitte zurück zu kommen und um die Bewilligung des Restes der zur Vervollständigung der Einrichtung erforderlichen Summe von rund 3,000 fl. zu bitten." The stated amount should have been used both for furniture and for bigger machines, specifically: 8 cabinets (480 fl.), 1 „*Lichtmaschine*" (500 fl.), 1 „*Compressionspumpe*" (500 fl.), 1 „*grosser Ruhmkorff*" (600 fl.) and 1 „*grosser Electromagnet*" (1,000 fl.). [15]

Building in Prague, Ovocný trh 7/562 (former Obstmarkt) where the old Institute of Physics was situated (today's look).

The new locality of the Institute was sometimes called (even in the university prints) Windberg, which often led to misunderstandings due to the confusion with Prague quarter Weinberge (Vinohrady). E. Mach mentions this in his letter to P. Salcher dated 27 June 1888, in which he describes the way to his Prague Physics Institute. He writes [16]: „*Der Name Windberg (auch das Krankenhaus befindet sich dort) ist dem Volk viel geläufiger.*" Still today the knowledge possessed by the inhabitants of Prague of the location of hospitals (sports stadiums or residences of pop music stars) seems to be greater than their knowledge of the addresses of scientific institutions.

Assistants at the Physics Institute

After his arrival in Prague, E. Mach took over the Physics Institute from his predecessor V. Pierre with his assistant, the private lecturer of mathematics (with the tutorial

Building in Prague, Viničná 3 (former Weinberggasse) where Mach's Institute of Physics moved in 1879.

language being German) at Prague Technical University, PhDr. Anton Karl Grünwald (1838–1920). He was Mach's coeval. He was of German nationality but, just as E. Mach once, he was willing to lecture in Czech. He held the position of Mach's assistant until 1870, when he was appointed an Associate Professor of Mathematics at Prague Technical University. There, he became the successor to Professor H. Durège (who, to the contrary, had passed to Prague University). As an aside, the previous conferment proceedings of A. K. Grünwald at Prague Technical University in 1863 took place concurrently with the conferment of F. Lippich for mathematical physics at the same institution (and also the adjunct of the Astronomical Observatory of Prague University Mořic Allé for mathematics). Another minor point of interest is that at the beginning of the 1890s, Grünwald's son Anton (1873–1932) studied under E. Mach at the German university (finally becoming a lecturer at the German Technical University in Prague, similarly to his father).

E. Mach chose his next assistants himself from among his students. These were in order: M. Neumann, V. Dvořák, W. Rositský, A. Haberditzel, O. Tumlíř, G. Jaumann and, as the last, J. Geitler von Armingen. With respect to the aforementioned and the data stated in Table 3, only a few supplementary comments will be added. Wenzel (Václav) Rositský (1850–1929) came from Prague. He started to attend Prague University after graduating from the Piarist Grammar School in Prague in 1872. He acted as

Physics Institute of Prague University				
Semester (Year)	Vorstand	Assistent	Hilfassistent	Cabinets-diener
- WS 1866/67	Prof. Victor Pierre → (1867: Technical University, Vienna)	PhDr. Anton Karl Grünwald (1838-1920)		Josef Zirm
SS 1867	University, Graz → SS 1867:			
1867/68				Franz Hajek (1839-?) (provisorisch)
1868/69				
1869/70		→ (1870: Professor of Mathematics, German Technical University, Prague)		
1870/71		PhDr. Clemens Neumann (1843-1873)		(? definitif)
1871/72		Vincenc Dvořák (1848-1922)		
1872/73				
1873/74	Prof. Ernst Mach			(See footnote[1])
1874/75		(1874: Privat Dozent) → (1875: Professor of Physics, University, Agram, Croatia)	V. Rosický	
1875/76 -		Václav Rosický (1850-1929)	Jaromir Wossika	
- WS 1877/78				
SS 1878		→ (1878: Assistant of the Astronomical Observatory, Prague-Clementinum)	A. Haberditzel	
1978/79 -		Andreas Haberditzel (1853-?)	PhDr. O. Tumlirz	
- SS 1880		PhDr. Ottokar Tumlirz (1856-1928)	1880: PhDr. Georg Pick (1859-1942)	
1880/81				
1881/82				
Physics Institute of Prague German University				
1882/83		(Privat Dozent)	(Privat Dozent) → Professor of Mathematics, German University, Prague	
1883/84	Prof. Ernst Mach			
1884/85			Privat Dozent PhDr. Otto Biermann (1858-1909) → (1885)	
1885/86 -		→ (1890: Vienna)	G. Jaumann (1863-1924)	
-1889/90				
1890/91-		Privat Dozent PhDr. Gustav Jaumann	Joseph Wanka (1867-)	
-1892/93		→ (1893: Professor of Physical Chemistry, German University, Prague)	→ (Navy Academy, Fiume)	
1893/94		PhDr. Joseph Geitler v. Armingen (1870-1923)	WS 1893/94: vacat SS 1894: Celestin Krupka (1871-?)	
1894/95	→ (SS 1895: University, Vienna)			
1895/96 -	University, Innsbruck → WS 1895: Prof. Ernst Lecher	→ (1903: Professor of Physics, University, Černivci)	vacat SS 1896: Franz Schicht	SS 1897: Eugen Hammer-Müller

Table 3: The staff of the Physics Institute of Prague (German) University in 1866–1897.

[1] The title of *„Inhaber der Weltausstellung-Forschrittsmedaille und der Broncemedaille der Prager Gewerbeausstellung 1874“* was added to the name of F. Hajek.

Mach's assistant in the years 1874–1878. During this period, he obtained, under Mach's tutelage, the degree of Doctor of Philosophy (1877) and teaching abilities for secondary schools (1878). He then became an assistant at the Astronomical Observatory of Prague University where he worked for 6 years (under directors K. Hornstein and, after him, L. Weinek). He then taught as a secondary school teacher in addition to other activities (e.g. he was excellent at shorthand, and in this field he held a number of significant posts in the Czech lands). In the publications from the time of his activity at Mach's Physics Institute, he followed up on the studies carried out by E. Mach and J. Wosyka on mechanical effects of spark discharges. He also experimented with Geissler discharge tubes.

The scientific curriculum of Joseph Geitler von Armingen (1870–1923) from Prague should also be mentioned. After four semesters at the German University in Prague in the years 1888/89–1889/90, he went to the university in Bonn to expand his physics education. There, under the tutelage of Gustav Hertz, he obtained his doctorate in philosophy in 1893 (his thesis was entitled *Reflexion elektrischer Drahtwellen*). After his return to Prague, he became Mach's assistant in 1894 as the successor to G. Jaumann. In 1896, already after Mach's departure for Vienna, he was appointed lecturer for physics at the German University in Prague. He retained the position of assistant at the Physics Institute until 1903, at which time he left for the university in Černivci. His scientific work related to the already mentioned topic of electromagnetic waves, as the conclusion to his cooperation with G. Hertz, and then in particular the issues of the properties and nature of cathodes and X-rays.

The already mentioned, J. Wosyka acted as an auxiliary assistant in Mach's Physics Institute. This was also the case with Georg Pick (1859–1942), a private lecturer and later Professor of Mathematics at the German University in Prague, and Otto Biermann (1858-1909), a private lecturer and later Professor of Mathematics at the German Technical University in Brno, or Joseph Wanka. Other individuals worked at the Physics Institute. Their names stand as co-authors in the bibliography of Mach's works. An example is Johann Sommer (1853–1929) from Bělá pod Bezdězem (Bohemia), signed up as a student of the first year at Prague University in 1873/74. He indicated his nationality as Czech and his father's occupation as *Landmann* in the registration. Together with E. Mach, he studied the propagation of explosion waves [17]. From 1883 he worked as a secondary school teacher. He is an author of several secondary school textbooks on mathematics and papers on teaching mathematics and physics. In the 1873/74 academic year, the 20-year-old Andreas Haberditzel signed up as a student of the first year of the Faculty of Philosophy of Prague University.

Some of E. Mach's Prague assistants and collaborators are mentioned in the foreword to the *Optisch-Akustische Versuche*, issued in 1873. This foreword may be interesting also for other remarks concerning Mach's research conditions in Graz and Prague [18]: *„Einige der hier beschriebenen Versuche habe ich schon vor mehreren Jahren in Graz begonnen, musste dieselben aber, wegen vollständigen Mangels aller Mittel, bald aufgeben*

und konnte sie erst jetzt wieder vornehmen. Auch diesmal ist mir bei manchen Theilen meiner Arbeit, anderer Uebelstände nicht zu gedenken, namentlich der morsche schwankende Boden desjenigen Locales, in welchem das physikalische Institut der Prager Universität untergebracht ist, sehr hinderlich geworden. [...] Ich kann hier nicht unterlassen, meinem Collegen Professor Lieben für die sorgfältige Versilberung werthvoller Planglläser, Herrn Dr. Vrba für die Herstellung einiger Krystallschliffe und meinen Schülern den Herren Hervert, Dufek und Janouschek für ihre eifrige Theilnahme an mehreren Experimenten, verbindlichst zu danken." Adolph Lieben (1836–1914) was a German Professor of General and Pharmaceutical Chemistry and the Director of the Chemistry Laboratory at Prague University from 1871 to 1875 (he moved to the University of Vienna in 1875 where he was the director of the 2nd Chemical Institute until 1906). Karel Vrba (1845–1922) was a Czech mineralogist, became private lecturer at Prague University in 1874, professor at the university in Černivci in 1876–1881, and then again professor at the Czech University in Prague. The Czech students Augustin Johan Dufek (born in ?1844 in Velká Bíteš, Moravia) and Josef Janoušek (born in ?1849 in Josefov, Bohemia) signed up for E. Mach's physics lectures at Prague University as early as in the winter semester of 1868/69.

Other Professional Activities in Prague

E. Mach's arrival at Prague University falls into the period of constitution of many student and professional associations, among them the Prague (German) Union of Natural History „Lotos" and the Union of (Czech) Mathematicians (and Physicists).

The Union of Czech Mathematicians and Physicists

From the two mentioned associations, E. Mach was professionally closest to the second one, the Union of Czech Mathematicians and Physicists (*Jednota českých matematiků a fyziků*). It was formed already before his arrival in Prague. The reason for its creation was the dissatisfaction of students with the nature of university lessons in mathematics and physics (reading aloud from text books or the lecturer's notes). After the first (private) initiative dating back to the 1860/61 academic year, the official student association called the Union for Free Lectures in Mathematics and Physics (*Spolek pro volné přednášky z mathematiky a fysiky*) was established in 1862. (The first statutes were adopted on 8 March 1862.) The initiators were four Czech students of the Faculty of Philosophy of Prague University, who were joined then by two German students. One was the aforementioned assistant of Professor V. Pierre, A.K. Grünwald, who even became the first chairman of the association in 1862–1863. Then he abandoned the association due to other interests. Discussion about the statutes of the Union was attended by Professor V. Pierre, physicist and the dean of the Faculty of Philosophy of Prague University at that time.

The first weekly meetings of the Union took place in the mathematics hall in Prague, Clementinum. In the beginning the Union was utraquistic. The first lectures were held in German (in accordance with the language that most students came into contact with at both university and secondary school). Interest in participation in the Union from the part of the students of German nationality was, however, non-existent in the end. The reason or result thereof was the Union opting for Czech. As of 1864, all minutes from meetings were written exclusively in Czech.

Through a change to the statues in 1869 there occurred a transformation to a professional association with a broader professional base and a new name: Union of Czech Mathematicians in Prague (*Jednota českých mathematiků v Praze*). Active members could be regular students of mathematics and physics at either Prague University or Prague Polytechnical Institute during their studies and 3 years thereafter, assistant professors, assistants and substitute teachers of the mentioned sciences. The category of contributing and honorary membership was also introduced, which allowed for other individuals to participate in the association (e.g., university professors). Lectures could be used in either of the main languages of the territory – Czech or German.

Among the functionaries and most devoted members of the association can again be found the most active of Mach's students. In the summer semester of 1868, the Secretary of the Union became A. Seydler. In the 1868/69 academic year, M. Neumann was elected the Chairman (and held the post up and including the 1871/72 academic year) and F. Houdek the Secretary (up to and including the 1873/74 academic year, then for a number of years held the newly established post of Director of the Union). M. Neumann was also Editor of the first Newsletter, which the Union began to publish in 1870. He reported on its pages about some physics demonstration instruments, e.g., Mach's „wave machine". Probably due to the enthusiasm for mathematics and physics of the members of the Union, E. Mach offered them his Physics Institute for the performance of lectures and instruments. There, on 12 June 1869, M. Neumann conducted the first lecture in experimental physics with a demonstration entitled (in Czech) *How waves on strings and a tuning can be visualised, i.e. the concentration and dilution of the air, nods and the higher tones.* At that time the Union had about 30 members. (Only one of them was of German nationality.)

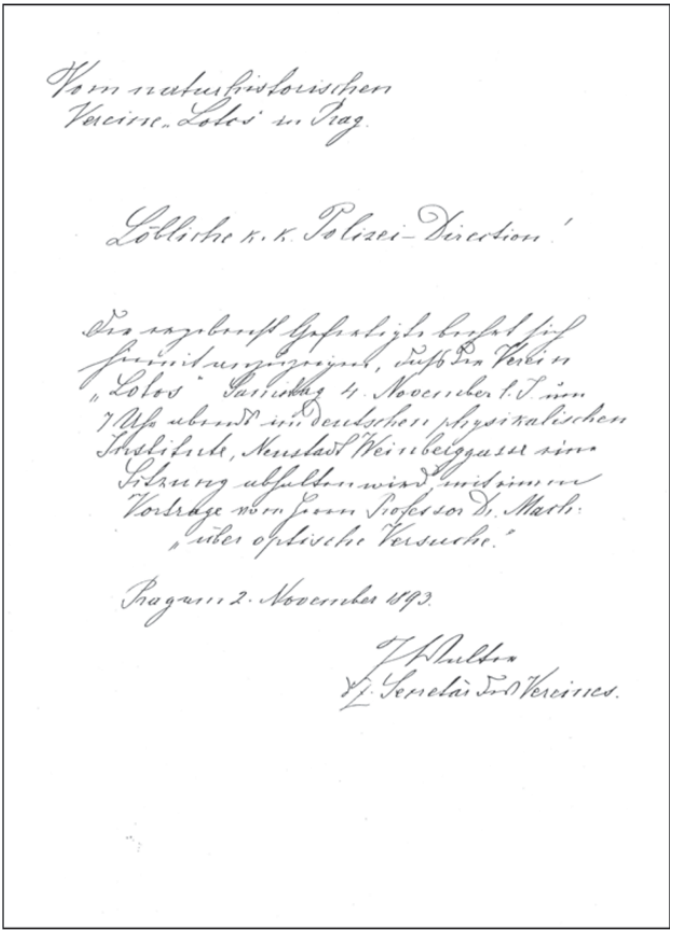
It is a question whether the growing number of physics topics in the lectures of the Union, apparent as of 1868/69, reflected in some way the arrival and teaching activity of E. Mach at Prague University. In any case, it can be of interest to note the theme of the then „interdisciplinary lectures" of J. Hervert (26 November 1868) *On the role of physics, on its relationship to physiology and psychology, and on its method*, or (29 May 1869) of his classmates F. Houdek *On Darwinism* and A. Seydler *On the mathematical idea of the theory of Darwinism* (all in Czech).

E. Mach became one of the first honorary members of the Union elected at the general meeting on 25 March 1870. He was elected for „his efforts to develop and expand the Union" (just as professor F. J. Studnička). He remained an honorary member

of the Union until his death and then posthumously (he remained on the list of deceased honorary members) [19].

The Prague (German) Union of Natural History „Lotos“

E. Mach participated even more through lectures and was organisationally involved in the activity of the Prague natural history association called „Lotos“, whose field of activity was broader and which, after its utraquistic beginnings, became more German.


Vom naturhistorischen
Vereine „Lotos“ in Prag.

Löbliche k. k. Polizei-Direction!

Der ergebenst Gefertigte beehrt sich
hiermit anzuzeigen, dass der Verein
„Lotos“ Samstag 4. November l. J. um
7 Uhr abends in dem dortigen physikalischen
Hörsaale, Neustadt Weinbergasse eine
Sitzung abhalten wird, in welcher
Vortrage vom Herrn Professor Dr. Mach:
„über optische Versuche.“

Prag am 2. November 1893.

J. Palla
d. Z. Secretär des Vereines.

Notification of E. Mach's lecture *„On Optical Experiments“* held in the *„Lotos“* Union in Prague on November 4, 1893.

This association was established already in 1848, firstly also as an association of Prague students and private lecturers (*Studentenverbindung*) with the aim of mutual self-education in natural sciences (in addition to physics, mathematics was represented scarcely). After approximately a year of activity, it also became a professional association, whose direction and activity was further assumed mainly by professors of Prague (German) universities. In 1895, it was incorporated into the statutes that German would officially be the only language of (internal) communication.

E. Mach was elected a full member at the general meeting of the Union on 28 April 1870 (together with the professor of Prague University, physiologist Ewald Hering, successor to J. E. Purkyně). Before this, however, he had lectured as a guest, first on 3 March 1868 on the theme *Einige neue akustische Versuche*. Mach's participation in the activities of the Union was quite naturally tied to the membership and activity of his predecessor V. Pierre and the membership and activity in the association of the majority of his German university colleagues, including mathematician H. Durège and F. Lippich (the latter was the editor of the association's journal *„Lotos" Jahrbuch für Naturwissenschaft* in the years 1884–1895).

At the general meeting on 25 January 1872, E. Mach was elected a member of the Union's committee, where he was active until his departure from Prague, i.e., for 23 years. In the years 1872–1876 he held the post of deputy chairman (during the chairmanship of Victor von Zepahrovich, a university professor of mineralogy). In 1877, the position of deputy chairman was taken over by E. Hering; the new chairman of the Union became the botanist Adolf Weiss. One of Mach's colleague in the committee of the „Lotos" Union was the eminent Czech mathematician, geodesist and geographer Karel Kořistka (1825–1906), at that time professor at Prague German Technical University. K. Kořistka had been an assistant to Ch. Doppler in Banská Štiavnica in 1848–1849.

The departure of E. Mach to Vienna in 1895 (as well as the departure of F. Reinizter, discoverer of liquid crystals, to Graz, and of E. Hering to the university in Leipzig), was commented at the general meeting of the „Lotos" Union on 8 February 1896 by the then-chairman, mineralogist and petrographer Friedrich Becke with the words [20]: *„Durch Berufung an die technische Hochschule in Graz verlor der Verein das ordentliche Mitglied Prof. dr. F. Reinitzer, ferner zwei Männer, deren gleichzeitiges Wirken an der Prager Universität auch in der Geschichte unseres Vereines ein leuchtendes Blatt bedeutet: Hofrath E. Hering, Professor der Physiologie, und Regierungsrath E. Mach, Professor der Physik an der deutschen Universität in Prag."* E. Mach and E. Hering were on this occasion nominated and elected honorary members of the Union (together with bookseller and benefactor of the Union F. Tempský).

During his membership in „Lotos", Mach was actively involved in its lecturing activity. He delivered 30 lectures, 1 to 3 lectures per year (Table 4). They took place directly in the Physics Institute and were accompanied by (surely effective) experiments and demonstrations. In the „Lotos" Union, most likely from Mach's impulse, some of Mach's students gave lectures (as guests or members, e.g., Seydler, Strouhal, Dvořák, Domalíp,

DATE	LECTURE
1868 (March 6)	**Mach, E.: Einige neue acustische Versuche**
1868 (November 5)	**Mach, E.: Neue Versuche über einige Principien der Mechanik**
?1869	**Mach, E.: Neue Construction der Influenz-Elektrisiermaschine**
1870 (February 2)	Neumann, M.: Über dem König's neuen acustischen Flammen-Apparat und Prof. Mach's Wellenmaschine (Literatur-Berichte: A. Wassmuth: Mach's akustische Vibroskope)
1870 (?)	Seydler, A.: Über das Nordlicht
1871 (January 12)	**Mach, E.: Über die Anfänge der Mechanik, hauptsächlich vor und in der Zeit Galilei's**
1871 (February 23)	Hervert, J.: Über Erscheinungen an rotierenden Körpern Strouhal, V.: Einige neuere auf die mechanische Wärmetheorie bezügliche Experimente
1871 (October 26)	**Mach, E.: Methode die einzelnen Theile des Gehörorgans richtig graphisch darzustellen**
1871 (December 7)	**Mach, E.: Eine neue akustische Anwendung des Spectralapparates**
1872 (January 25)	**Mach, E.: Über Doppelbrechung amorpher Substanzen (mit Demonstrationen an Glastangen und Prismen von halbflüssigen Leim)**
1872 (October 31)	**Mach, E.: Über stroboskopisch-akustische Experimente**
1874 (January 22)	Dvorak, V.: Über die Kundt'schen Staubfiguren
1873 (March 20)	**Mach, E.: Über Brechung des Schalles und Interferenz des Lichtes (ein mit Experimenten begleiteten Vortrag)**
1873	Seydler, A.: Über den Venus-Durchgang am 8. u. 9. Dezember 1874
1874 (February 5)	**Mach, E.: Einige Experimente über Gleichgewichts- und Bewegungsempfindungen**
1875 (February 20)	**Mach, E.: Über einige optische Versuche**
1875 (April 17)	**Mach, E.: Über anomale Dispersion**
1875	Lippich, F.: Über die Abhängigkeit der Absorption des Lichtes von der Dichtigkeit der Flüssigkeiten
1876 (February 12)	Wosyka, J.: Einige mechanische Wirkungen des Elektrischen Funkens
1876 (April 29)	**Mach, E.: Doppelbrechung bewegter Flüssigkeiten**
1876 (December 16)	Lippich, F.: Experimentelen Studien über die Abhängigkeit der Lichtwellenlänge von der Intensität (berichtet über eine Experimentaluntersuchung, die Frage der Abhängigkeit der Lichtwellenlänge von der Intensität betreffend)
1877 (January 27)	**Mach, E.: Über Explosionswellen**
1878 (April 6)	**Mach, E. „führt einige stroboskopische Versuche aus“**
1878 (May 11)	Schmidt, G. [Professor at the German Technical University in Prague]: Über den Begriff Masse [of E. Mach and others]
1880 (February 17)	**Mach, E.: Über die Theorie des Radiometers und ein an die Radiometeranordnung anknüpfender Versuch**
1881 (January 15)	**Mach, E.: Demonstration und Erklärung einiger elektrischer Versuch**
1881 (May 7)	Lippich, F. „vorgezeigte ein Polarisationsapparat grosser Empfindlichkeit“
1882 (April 29)	**Mach, E.: Über stationäre Strömungen der Electricität**
1883 (February 3)	**Mach, E.: Experimentalvortrag zur Electricität**
1883 (March 3)	**?Mach, E.: Über des Blitzableitersystems Melsens**
1884 (May 3)	**Mach, E. „hält einen durch Experimente erläuterten Vortrag aus dem Gebiete der Optik“**
1884 (December 6)	**Mach, E. „erläutert einige physikalische Experimente, betreffend Explosionen und damit verknüpfte Erscheinungen"**
?1884 (December 20)	Tumlirz, O.: Über die elektromagnetische Drehung der Polarisationsebene des Lichtes
1885 (December 5)	Tumlirz, O.: Verhaltung des Bergkristalls im magnetischen Feld
1886 (October 30)	**Mach, E. „demonstriert der Schnelligkeit der Schallwellen und physikalischen Apparaten“**
1886 (November 27)	Tumlirz, O.: Über die Geschwindigkeit der Vorpflanzung der Electricität
1887 (February 12)	Tumlirz, O.: 1.Über die chromatische Abweichung des Auges 2. Die Umkehrung der Natriumlinien
1887 (February 26)	**Mach, E. „demonstriert der Polarisation an zwei physikalischen Apparaten“**
1887 (October 15)	**Mach, E. „erklärt einige optische Versuche und der Assistent Jaumann demonstriert einen Schutzring –Elektrometer mit continuirlichem Ablesung"**
1887 (November 26)	Tumlirz, O.: Bericht über das Verhältnis zwischen die Stromintensität, Widerstand und Leuchtkraft galvanisch glühender Platindrähte
1888 (October 13)	**Mach, E.: Bericht über die in Meppen ausgeführten ballistisch-photographischen Versuche**
1888 (November 10)	Jaumann, G.: Bericht über die neuen Experimente über die elektrische Entladung
1890 (December 13)	**Mach, E.: Neue Demonstrationen mit einem Vortrag aus dem Gebiete der Mechanik verbundene**
1891 (November 21)	Jaumann, G.: Über einen neuen Elektrometer, mit Experimenten
1892 (January 23)	**Mach, E.: Optische Versuche**
1893 (November 4)	**Mach, E.: Über optische Versuche**
1896 (May 8)	Geitler, J.: Vorlesung über Kathodenstrahlen [held in Litoměřice, Bohemia]
1896 (May 9)	Jaumann, G.: Über die Beugung der Katodenstrahlen durch statische Electricität

Table 4: Lectures held by E. Mach and his disciples (resp. colleagues) at meetings of the Prague (German) Union of Natural History *„Lotos“*.

and Wanka). The broad spectrum of members of the Union could have contributed to their (mutual) interdisciplinary communication and inspiration (which had an important place in Mach's work).

On the pages of the Journal published by the Union „Lotos", a total of six of E. Mach's articles appeared between the years 1870–1884 (including one small notice) and a number of reports on his publications or accounts of his lectures, as well as some articles by E. Mach's students (four articles by O. Tumlíř from the years 1880–1884, two of which dealt with the expansion and bending of sound waves; one article on mathematics by J. Wanka from 1891) [21].

Resignations

In the 1872/73 academic year, 34-year-old Professor E. Mach became the dean of the Faculty of Philosophy of Prague University, where he then held the position of the rector of the University: in 1879/80 (vice-rector the year after) and again for a part of the 1883/84 academic year at the German University. This was a period of intense nationalism, shortly after the division of Prague University. One can read about Mach's stand on these issues in different places [2, 3, 4, 22]. Testimony to his being tired of the tug-of-war of the time is his stepping down as rector in January 1884 (officially on grounds of health problems). His position was taken over by his colleague Professor F. Lippich. The newspaper *Prager Tagblatt* from 8 December 1884 commented on this, in an overview of the most important events of the year 1884, by these words: *„Januar 12. Der Rector der deutschen Universität in Prag, Prof. Mach, resigniert wegen wiederholter Conflicte mit dem Unterrichtsministerium, zuletzt wegen der Angelobungsansprache an der theologischen Facultät."*

In 1884, Mach also gave up his membership in the Royal Bohemian Society of Sciences, of which he had become a full member in 1871 and in which, during the first year, he was actively involved in lecturing. He officially justified his step by stating a lack of time and other obstacles. The Society celebrated a centenary of its existence (as an opened institution) in that year. Shortly before the festive meeting, held on 4 December 1884, three more professors of the German University announced their secession from the Society. These were mathematician H. Durège, geologist G. Laube and botanist M. Willkomm. The newspaper *Prager Tagblatt* from 7 December 1884 commented on this situation: *„Herr Prof. dr. Mach, Mitglied der Wiener Akademie der Wissenschaften, ist schon früher ausgetreten mit der Motivierung, er könnte unter den herrschenden Verhältnissen nicht Mitglied der Gesellschaft bleiben."* (Incidentally, K. Kořistka held the post of the Scientific Secretary of the Society just in those troubled times.)

Leaving for Vienna

By a decision of the sovereign dated 5 May 1895, with effect from 1 October 1895, E. Mach was summoned to be a full-time professor of *Philosophie, insbesondere Geschichte und Theorie der induktiven Wissenschaften*, a chair created especially for him. His successor at the German University in Prague, by a decree dated 15 September 1895, with effect from 1 October of the same year, was 38-year-old Ernst Lecher (1856–1926), who had been before this appointment a full-time professor of physics at the university in Innsbruck. In the proposal for the occupation of the professorship made available by E. Mach's departure, the following individuals were also considered as candidates: Franz Klemečić, associate professor at the university in Graz (in second place) and Carl Exner, a full-time professor at the university in Innsbruck (in third place). E. Lecher was recommended, apart from other things, as a person *„who is able to inspire his students"*. This was surely an encouraging statement in the search for a replacement for such an excellent pedagogue as E. Mach was. E. Lecher's teaching responsibilities were defined as the due representation of the nominated field by at least five hours of lectures per week each semester and by one collegium publicum on a special topic in each third semester. He was awarded an annual salary of 2,000 fl. (plus other system perquisites). E. Lecher remained in Prague for 14 years. In 1909, he left for the university in Vienna where he concluded his professional career. His scientific interest was oriented towards the field of wire(less) telegraphy [23].

Conclusion

Through his pedagogical and scientific activity, E. Mach significantly influenced the development of physics in the Czech lands – from the secondary school level to the university level. In his lectures, he gave the students the opportunity to access deeper opinions and historical-philosophical perspectives regarding physics and its principles. He provided interested persons the possibility to carry out scientific work in his institute. This work under E. Mach's tutelage resulted in a number of interesting publications by his students in the field of acoustics and aeromechanics: the study on reflection, refraction and the velocity of the sound waves propagation in various medias (Č. Dvořák, Š. Doubrava), on the mechanical effects of spark discharges and the phenomena accompanying transit of high-speed projectiles through gases (a topic in which J. Wosyka, V. Rosický, J. Sommer, O. Tumlíř, C. Kögler, J. Weltrubský, G. Gruss, J. Simonides, E. Wentzel and L. Mach participated) and which was based on elaboration of the current or developing new experimental methods. Not all of Mach's students had the possibility to continue with their academic careers. Most of E. Mach's Prague physics students applied the experience and knowledge they acquired under his tutelage at secondary schools. Some of them

launched a business in the production of physics instruments and aids (M. Neumann, J. Hervert, F. Houdek, and Š. Doubrava). It appears that in Mach's lectures and in his Physics Institute there dominated an atmosphere that allowed for the national conflicts of the time to be spanned.

In this article, attention was focused on E. Mach and his Prague physics students and colleagues. Mach's scientific impact and contacts during his Prague stay, however, were far more complex and can be followed in many other fields. Pieces of correspondence with Czech chemist Bohuslav Brauner (1855–1935) (which were discovered in Brauner's written heritage by S. Štrbáňová) can serve as an interesting illustration of that (see the Supplements). Brauner studied chemistry at Prague Technical University but he also attended lectures at Prague University, including physics lectures by E. Mach. Then he continued his studies abroad (in Heidelberg under R. W. Bunsen and in Manchester under H. Roscoe). It seems, that Mach's letters of recommendation helped Brauner open the door to leading foreign laboratories. In 1882, he became a lecturer, in 1897 a professor of chemistry at Prague Czech University [24].

E. Mach was remembered fondly and with appreciation by his Prague students. Next generations of Czech physicists, philosophers and historians of science have been referring to him in the form of anniversary celebrations and historical studies ever since. The Ernst Mach Honorary Medal for Merit in Physical Sciences was established on 12 December 1995 by the Academy of Sciences of the Czech Republic as the most prestigious acknowledgement of scientific results achieved in the field of physics.

The Ernst Mach Honorary Medal for Merit in Physical Sciences established by the Academy of Sciences of the Czech Republic.

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Supplements

E. Mach to F. Koláček (Prague, 18 April 1877, 8 pages) [8]

Hochverehrter Herr!

Zunächst muss ich Ihnen wiederholen, dass es mich ungemein gefreut hat, Sie persönlich kennen zu lernen. Anknüpfend an unser Gespräch erlaube ich mir nun folgendes beizufügen. Unsere Versuche über anomale Dispersion sind veranlasst worden durch die Bemerkung, dass die Ordnung der Farbenringe an einem Newtonschen Glase, welches statt Luft Fuchsin enthält, dieselbe ist, wie an einem Glase mit einer Luftschichte. Wäre das genau beobachtet und wahr, so wäre das geradezu anfassbar. Es schien uns also geboten zu fragen ob das nicht eine Fuchsinlösung war, die noch keine anomale Dispersion zeigte und ob nicht Lösungen, die welche bei der Brechung Anomalie zeigen diese auch dann die Interferenz verrathen. Gerade den zweideutigen Versuchen von Quincke gegenüber scheint mir eine solche Darstellung theoretisch wichtig. Die Frage ist wohl auch deshalb nur nicht gestellt worden, weil die experimentelle Beantwortung zu schwierig war.

Publicirt haben wir bis jetzt nur zwei kurze Noten in akadem. Anzeiger 1825 N^o 7 und N^o 10. Ergänzend muss ist noch beifügen:

Von den in N^o 7 beschriebenen Versuchsmethoden geben 1 und 2 sehr nette Resultate. Die 4^e Methode ist zu complicirt und umständlich, sie ist nicht empfehlenswerth und wir haben sie bald wieder ganz aufgegeben.

Die Methode 3 hat ~~eine~~ ein ganz klares negatives Resultat gegeben.

Denken wir uns einen Doppelkeil der eine Planplatte bildet, Durchschnitt dargestellt und noch parallel der Ebene des Papiers in 2 Theile getheilt. Der eine Theil des Doppelkeile ist mit Alcohol, der andere mit Alcohol-Fuchsinlösung gefüllt. Wir lassen nun die beiden Jaminschen Strahlen durch die beiden Theile gehen, bringen sie zur Interferenz und lösen die Erströmung spectral auf (nachdem wir die Interferenz vermöge der erwähnten Polarisationsvorrichtung wiederaustritt gemacht haben).

Die Spectralstreifen schwanken zwar wen man die Keile verschiebt, also die Platte verdickt und verdünt, alle dieses Schwanken rührt nur von Fehlern her, den es verschwindet, wem das ganze Apparat noch in ein Alcoholcuvette mit Plangläsern versenken wird.

Da man bei der Dicke der Keile, wen nicht alles Licht absorbiert worden kann soll, nur mässige Concentrationen anwenden kann, da ferner die Versuche mit festen Fuchsinplätschen ein positives Resultat gegeben haben so folgt:

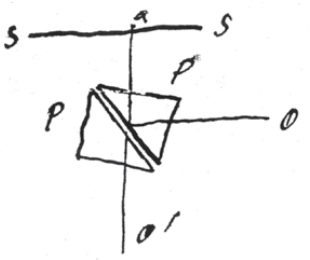
Es ist nicht einerlei, ob ein Strahl eine Schichte D von der Concentration C oder ob er eine Schichte $\underline{nD}$ von der Concentration $\underline{C}$ durchsetzt, wie man a priori glauben

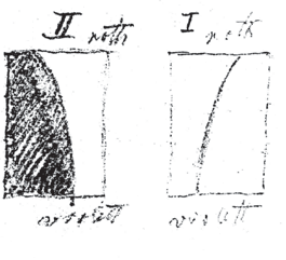
könnte, vielmehr ist zur Wahrnehmung der Dispersionsanomalie eine gewisse Grösse der Concentration notwendig.

Etwas ähnliches hat später Lippich in Bezug auf Absorption gefunden, was bei dem Zusammenhange von Absorption u. Dispersion nicht wunderbar ist.

Werde man feste düne Fuchsinplatten angewendet, wie man sie durch Aufgiessen der Lösung auf eine erwärmte plane Glasplatte erhält, so tritt die Anomalie bei der Interferenz deutlich hervor. Die Discontinuität der Brechungsexponenten zeigt sich aber nicht, wie sie ebenfalls gesehen haben. Wo ist die hin geratten?

Das in N^o 10 beschrieben Verfahren der totalen Reflexion möchte ich Ihnen empfehlen.

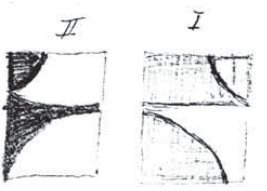




Betrachtet man ein horizontale Spalte SS durch die Prismencombination PP' von O oder O' aus nach den man das Auge durch ein Prisma mit verticaler Dispersionsrichtung (Violett nach unten) bewaffnet hat, so sieht man in O das Spectrum I in welchem der ultraviolette Theil von der gewöhnlichen, der helle von der totalen Reflexion herrührte. In P' hat man das Spiegelbild der Escheinung (II), nur entspricht natürlich dem helleren Theil von I ein vollkomen schwarzer.

Bei der erwähnten Versuchsanordnung ~~treten~~ tritt in I die Grenzcurve nicht in voller Deutlichkeit auf, weil jeder Spaltenpunkt zur ~~B~~ei Erzeugung seines Bildes einen Regel ins Auge stricht, der die Pupille zur Basis hat, diesen Strahlen also unter verschiedener Incidenz reflectirt wurden. Deshalb ist es zweckmässig Collimator zu Beobachtung mehr eines Spectralapparates auf ∞ einzustellen, PP dazwischen zu bringen, die Spalte horizontal zu stellen und von das Ocular ein Prisma von verticaler Dispersionsrichtung und mässiger Dispersion zu befestigen. Hat das Prisma ~~em~~ (à vision directe) eine grössere Öffnung, so könnte es noch besser vor das Objektiv des [?]Beobachtungsrohres bringen. Bringt man zwischen PP statt eine Luftschichte eine Fuchsinlösung, so sehen die Erscheinungen so aus.

In I liegt δ total reflectierte Theil rechts und ist gegen den einfach reflectierten der links liegt durch Curven abgegrenzt.



II ist beiläufig das Spiegelbild von I, dem total reflectierten entspricht ein schwarzes Bild. Doch ist II ~~nicht~~ bei Fuchsin überhaupt nicht mehr massgebend, weil die Strahlen, welche δ total Reflexion nahe kommen sehr [?]strict durch die düne Fuchsinstrickte gehen, also δ auch eine bedeutende Dicke durchsetzen also stark absorbiert werden. Es combiniert sich also ein mittlere Theil die total Reflexion u. die Absorption. Fig I. und auch δ oben Theil von Fig II gibt aber meines Erachtens die beste Einwürfen am wenigsten ausgesetzte Darstellung δ anomalen Dispersion.

Ich glaube das dieses Gebiet eben weites Unklarheiten enthält, eine Fundgrube neuer physikal. Wahrheiten ist. Man muss aber nichts mit einer Theorie um die Erscheinungen gehen, sondern vielmehr sich den Erscheinungen hingehen und reine Gedanken ans denselben ertröpfen wie es Newton getan hatte.

Die Erscheinungen sagen mir deutlich, das Lichtgeschwindigkeit und chemische Constitution eng zusammenhängen. Sie werden mehr sagen als jede gegenwärtige Molekulartheorie herausdüfteln wird. Nimmt man photochemische Erfahrungen hinzu, so kann man leicht auf den Gedanken kommen, dass die Lichtschwingungen chemische Schwingungen sind. Sie bestehen in beginnender chemischer Trennung und Wiederzusammensetzung. Körper die mit grosser Affinität vorhanden sind, werden so zu sagen einen grossen chemischen (und optischen) Elasticitätsmodul haben. Ist ein Körper hoch zusammengesetzt so können die verschiedenen Bestandtheile mit verschiedenen Elasticitätsmodul am einander gebunden sein, es können also sehr ungleiche Massen unter sehr ungleichen Verschriebungskräften schwingen, daher a priori gar keine Regel über die Abhängigkeit von Welten Schwingesdauer und Lichtgeschwindigkeit aufzustellen ist.

Dass das Medium des leeren Raumes chemisch einfach ist, kann keinen Einwurf bilden. Wir wissen nichts darüber.

Ich begreife nach dieses Auffassung im Prinzip, das leuchtende Explodieren des Kanallgasses. Die Vereinigung von H und O ist eben von der Lichtstrasse ganz nicht wesentlich verschieden. Es folgte der grossen Vereinigungsschwingung eine Reihe kleinerer Schwingungen um die chemische Gleichgewichtslage. – Eben so verständlich wird mir ohne dass ich an Molecule, überhaupt an Räumliches denke, dass die Netzhaut durch das Licht chemisch afficirt wird.

Geht man der chemische Elasticitätsmodul (der sich in δ Lichtgeschwindigkeit äussert) mit der chemischen Vereinigungsarbeit (Verbrennungswärme) in einer Verbindung Wahrscheinlich nicht. Muss man auch die chemischen Vorgänge nicht notwendig räumlich denken, so können in doch ganz oder zum Theil in den Eukleidischen Raum fallen. Geht zum B. in Wasser Electrolyse vor, so geht die chemische Trennung in der Stromrichtung vor und in keiner andern.

Die Versuche von Kerr, die Drehung der Polarisationsebene durch δ Strom u. s. w. scheint endlich zu passen, man braucht also an der Bewältigung der Dopelbrechung auch

nicht zu verzweifeln. Es würde mich sehr freuen, wen Sie in dieser Thema Geschmack finden würden. Sind Sie in irgendwelchen Punkten anderer Meinung, so wußte ich mir gar nichts [?]dweint. Was Ihnen einfällt und was Sie nicht ausführen können will ich nach Möglichkeit gern besorgen.

Mit dem Wunsche Ihres besten Wohl gewis herzlichst grüsssend

Ihr ergebenster E. Mach.

Prag 18 April 1877

E. Mach to F. Koláček (Prague, 23 June 1895, text on the reverse side of Mach's visiting card) [8]

H.H.C!

Ich wollte Ihnen gestern persönlich danken für Ihr freundliches Geschenk und mich zugleich von Ihnen verabschieden. Sie waren alle ausgestossen und niemand hat mir geöffnet tritt. Hochachtungsvolles Gruss

Ihr ergebenster E. Mach

Prag 23/VI 95

Recommendation letter by E. Mach on B. Brauner (addressed most probably to Bunsen, Prague 14 October 1878, 1 page) [24]

Hochverehrter Herr College!

Den Überbringer dieser Zeilen, Herrn B. Brauner, habe ich als einen sehr begabten und strebsamen Studiosus kenen gelernt und erlaube mir hiermit, Ihnen denselben bestens zu empfehlen. Es hat mir sehr leid gethan, dass ich Sie bei meinem letzten Besuche in Heidelberg nicht angetroffen habe.

Ihnen das beste Wohlsein und die schönsten Erfolge wünschend

hochachtungsvoll

Ihr ergebenster E. Mach

Prag 14 Oct. 1878

E. Mach to B. Brauner (Prague, 5 December 1878, 2 pages) [24]

Hochverehrter Herr!

Wen Sie H. Hofrath Bunsen freundlich aufgenomen hat, so haben Sie das ohne Zweifel nicht meinem Schreiben sondern sich selbst zu danken.

Mit dem Brief am Prof Quincke bitte ich nach Belieben zu verfahren, da derselbe ja keine Geheimnisse enthält. Die Übergabe des Briefes wurde Sie Quincke gegenüber

selbstverständlich zu nichts zwingen, obgleich dieselbe anderseits ohne Belang wäre, wen Sie das Laboratorium nicht besuchen könen.

Ich hatte es für einen glücklichen Gedanken von Ihnen, sich den Tagesfragen d. organ. Chemie für eine Zeit wenigstens zu entziehen. In Prag wurde einem Bedürfnis entsprochen, wen sich jemand gerad mit Rücksicht auf die von Bunsen vertetene Richtung (f. physikal. Chemie oder chemische Physik) habilitirte.

Indem ich Ihnen den schönsten Erfolg wünsche, verbleibe ich mit der Versicherung, das Ihre verbestriebene Höflichkeit fast das Einzige ist, was ich an Ihnen auszusetzen habe.

Hochachtungsvoll

Ihr aufrichtiger E. Mach

Prag 5 December 1878

E. Mach to B. Brauner to England (Prague, 6 January 1881, 1 page) [24]

Verehrter Herr Doctor!

Es hat mich ungemein gefreut, von Ihnen einige Zeilen zu erhalten und zu sehen, dass Sie sich in England gefallen. Sie haben nirgends wie da so schöne Gelegenheit sich einen freien objectiven Blick anzueignen und die Befangenheit in hergebrachten Theorien abzulegen.

Ihre freundlichen Wünsche herzlich erwidernd und Ihnen die besten Erfolge wünschend

Ihr aufrichtiger E. Mach

Prag 6 Jäner 1881

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