Hermann von Helmholtz
(1821-1894)

Notes for
Multimedia Fluid Mechanics
Cambridge University Press, 2008

The breadth of Helmholtz's interests and contributions is outstanding. He is one of the rare scientists able to be creative in domains, as diverse as medicine, anatomy, physiology, acoustics, fluid mechanics, physics, music, aesthetics, epistemology… Although he was a universal mind, he insisted on his preference for physics, both theoretical and experimental. He was among the too rare scientists able to combine fundamental research and practical applications related to everyday life. Two years before his death, he gave us the following warning, which is still pertinent today: *'Whoever in the pursuit of science, seeks after immediate practical utility may rest assured that he seeks in vain.'* The applicability of science is a consequence of research and not its sole goal, since the creativity requires the freedom to speculate on fundamental issues. The life of Helmholtz perfectly illustrates his point.

His life

Berlin (1821-1848)

Hermann Ludwig Ferdinand Helmholtz was born in Potsdam (Prussia) on August 31st 1821. His mother was a descendent of William Penn, who founded Pennsylvania, and his father was a teacher of philosophy and literature. As a boy he was fragile, often ill, and had difficulties in memorizing matters that he could not first understand, which indeed gives a better mastery of the topics afterwards. At the age of 9 he entered the Potsdam Gymnasium where his father was teaching. He was the first child of a family of five and, since his father had difficulties in paying for their studies, he was sent to the 'Royal Medical and Surgical Friedrich-Wilhems Institute' in Berlin, where he got a scholarship under the commitment to be a military surgeon for at least 8 years. He was therefore forced to choose medicine, although his inclination was already for physics, which he studied by himself, reading Laplace, Biot and Bernoulli. After writing his dissertation on the nervous system of vertebrates, where he proved that nerves originate in ganglion cells and thus refuted the vitalist arguments defended by his PhD advisor, Johannes Müller, the most famous German physiologist at that time, he obtained at the age of 21 his doctorate in medicine.

De Fabrica Systematis Nervosi Evertebratorum,
Berlin, 1842

Although he served as a surgeon in the regiment of the Royal Guards in Potsdam since 1843, he resumed his research in physiology with a clear goal towards physics. He first studied the production of heat by muscle action, and, assuming that matter is made of particles which interact by central forces, he proved, independently of Joule and Mayer, that energy is conserved, since he showed that the total energy of such a system of particles remains constant. He presented his work before the Physical Society of Berlin on July 23rd 1847, giving an outstanding lecture where he introduced the concept of potential energy.

On the conservation of force,
G. Reimer, Berlin, 1847

Due to the fame he has thus acquired, he managed in 1848 to free himself from his military duty and got his first academic position at the Anatomical Museum and at the Academy of Fine Arts in Berlin as teacher of anatomy. To get started in this field which was new to him, he wrote a review of works in theoretical acoustics which was published in *Fortschritte der Physik* in 1849, where he considers three research approaches to study the sensation of sound: physics, physiology and psychology.

Königsberg (1849-1855)

In 1849 he was nominated assistant professor and director of the Physiological Institute in Königsberg. The same year he married Olga von Velten who was the daughter of a physician and with whom he had two children. Helmholtz first studied the propagation of nerve impulses and was able to measure a velocity of 30 m/s for frogs' nerves.

On the velocity of propagation of nerve impulses
Comptes Rendus, 1850

Starting from this physiological problem Helmholtz got interested in electrodynamics and he discovered the law of electric current in an inductive circuit that he published in 1851.

On the course and the duration of electric currents induced
by current fluctuations
Poggendorffs Annalen, 1851

In 1851 he invented the ophthalmoscope, which revolutionized ophthalmology and is still in use today to observe the retina, and later in 1864 he also invented the ophthalmometer, which measures the eye's curvature.

Description of an ophtalmoscope for the examination
of the retina in the living eye
Verlag von A. Forster, Berlin, 1850

He also studied the theory of light and was interested in understanding the perception of colors.

On the theory of complex colors
Poggensdorf Annalen, 1852

On the composition of spectral colors
Poggensdorf Annalen, 1855

During his stay in Königsberg, Helmholtz had the chance to meet William Thomson (latter Lord Kelvin) who was in Kreuznach accompanying his wife for a medical cure. This started a lifelong friendship between two exceptional scientists, which triggered a strong mutual influence of eminent German (Helmholtz and Kirchhoff) and British physicists (Kelvin, Green, Stokes, Maxwell) in the second half of the 19th century. Helmholtz recalled his first encounter with Thomson: *'I expected to find in him, who is one of the foremost mathematical physicists of Europe, a man somewhat older than myself, and I was not a little astonished when a light-blond youth of girlish appearance came towards me… With respect to analytical acumen, clarity of thought and versatility he surpasses every great scientist I have met; indeed I myself feel at times a little stupid in his presence.'*

Bonn (1855-1858)

In 1855 he obtained a position of full professor of anatomy and physiology at Bonn University. Although his father enjoined him to focus on medicine only, Helmholtz resumed his deep interest to physics, as he expressed in a letter written in 1857 to the curators of Bonn University: *'Physics has always been the science that most attracted my interest ; essentially, it is external constraining circumstances that have led me to physiology through medicine. What I have accomplished in physiology is essentially based on physical grounds'*. The three years he spent in Bonn were very fruitful, although the lack of experimental facilities at Bonn obliged him to focus more on theory and to develop new mathematical tools. He also had to face problems with some of his students who were complaining about the fact that he was using some mathematics, *e.g.* cosines, during his course of anatomy.

Handbook of Physiological Optics, 1st volume, 1856

Heidelberg (1858-1871)

In 1858 Helmholtz moved to Heidelberg where he occupied the chair of physiology at the university, where he had a fruitful collaboration with his physicist colleagues, Bunsen and Kirchhoff. Year 1858 could be considered his 'annus mirabilis', since he published that year his main contributions to acoustics and fluid dynamics: *'On the combination of tones'* , *'On air vibrations in pipes with open ends'* and *'On integrals of hydrodynamic equations which correspond to vortex motions'*. But in 1859 he successively lost his father and his wife, leaving him with two young children to care for. He then had health problems and had to interrupt his research for about one year. When he resumed his scientific work he completed his 'Handbook of Physiological Optics', plus two papers, one on the musical temperament and the other on the Arabic-Persian musical scale. His handbook, published in two volumes respectively in 1856 and 1867), is considered to be his masterpiece on optics, where he proposed to characterize the colour by three parameters: brightness, hue and saturation In 1861 he married Anna von Mohl, who was much younger than him, and this initiated the most active and productive years of his life. In 1863 he published his masterpiece on acoustics, entitled *'The sensations of tones*', a physiological basis for the theory of music.

On air vibrations in pipes with open ends,
Journal für reine und angew. Mathematik, 1858
On integrals of the hydrodynamic equations which correspond to vortex motions,
Journal für reine und angew. Mathematik, 1858
On the Sensation of Tone as a Physiological Basis for the Theory of Music, 1863
Handbook of Physiological Optics, 2nd volume, 1867
The discontinuous motions of fluids
Monthly Proc. Ann. Sci. Berlin, 1868

In 1870 he obtained the chair of physics in Berlin which was vacant after Magnus' death. After tough negotiations about the conditions, he accepted the position and obtained : the construction of a new Institute of Physics, the guarantee that he will decide himself who can use it, an apartment for his family at the institute, and finally a substantial high salary. He got the position and moved to Berlin in 1871.

Berlin (1871-1894)

Helmholtz was at that time the most respected and the most influential scientist in Germany. It is striking to notice that his friend William Thomson, who has become Lord Kelvin, was at the same epoch the leader of British science, combining too outstanding theoretical works with important responsibilities in th industrial development of the British empire, such as rg wiring of transatlantic telegraph and telephone systems. In 1882 he was enobled and became von Helmholtz. Four years later, having the support of Bismarck, he founded with Siemens, to whom he had some family connection, the Physico-Technical Imperial Institute in Berlin and became its first director, a position that he held for the rest of his life. During the 23 years he spent in Berlin he focussed on the theory of electrodynamics, developed by Ampère, Maxwell and Hertz. He also pursued his research on acoustics and published a paper on *'The telephone and the quality of sound'*. He also contributed some key papers on thermodynamics. He was often travelling all over Europe, in Switzerland, France, Spain and Italy. In 1877 he was for one year the rector of Berlin University, giving his inaugural speech *'On academic freedom in German universities'*, which is still very pertinent today. In 1888 he became the first president of the 'Physikalisch-Technische Reichsanhalt', which implied a lot of administrative duties, although he managed to pursue his research. He thus managed to launch a new direction of research and studied atmospheric motions, where he made several major contributions, showing that the presence of discontinuous boundaries between stratified air layers become nonlinearly unstable (called today Kelvin-Helmholtz instability), which thus result in turbulent mixing in the atmospheric boundary layer, a phenomenon then confirmed by measures on board meteorological balloons.

Theory of anomalous dispersion', Pogendorffs Annalen, 154, 1875
Cyclones and thunderstorms', Deutsche Rundschau, 1876
On academic freedom in German universities', Rectoratsrede,
15 October 1877
The telephone and the quality of sound', Wiedemanns Annalen, 5, 1
Studies on electrical boundary layers', Wiedermanns Annalen, 7, 1879
On the physical significance of the principle of least action',
Crelle's Journal, 100, 1886
On the formation of clouds and thunderstorms', Physikkalische Gesellschaft,
22 October 1886'
Counting and measuring as viewed from the standpoint of the theory of
knowledge', Philosophische Aufsätze, 1887

On atmospheric motions', Verhandlungen der Physikalischen Gesellschaft zu Berlin, 25 October 1889
The energies of waves and winds', Wiedemanns Annalen, 41, 1890

By 1885 he began to have health problems and the headaches he suffered all his life long became worse. He was also obliged to interrupt his activity for long periods due to recurrent depressions. After refusing twice to go to the United States, he finally accepted in 1893 and was sent by the German government as delegate to the Electrical congress in Chicago. He was reluctant about leaving for such a long journey and put as a condition for his acceptance that his wife could accompany him, which resulted in a very interesting set of letters sent by Mrs. Helmholtz to her daughter where she described their American trip. While he returned from United States, he fell down while disembarking from the ship and was badly injured. On July 12th 1894, Helmholtz had a cerebral attack, from which he never recovered, and died in Berlin on September 8th 1894.

Handbook of Physiological Optics, 2 volumes, 2nd edition, 1896

His contributions to fluid mechanics

By the middle of the 19th century acoustics was a fast growing branch of physics, and a perfect research topic for someone like Helmholtz who loved both music and mathematics. He thus became interested in studying the perception of sound and the physiology of hearing. This field was very controversial at that time, since the theory of fluid mechanics was based on Euler's equation which failed to solve many practical problems of fluid mechanics and acoustics, and scientists were also fighting about the relevance of the recently discovered Fourier analysis. This is why Helmholtz wanted to base the science of acoustics on clear experimental facts, before trying to reach some theoretical consensus. He explained his motivation for acoustics in a letter written in 1857: *'I have always been attracted by the wonderful, highly interesting mystery : it is precisely in the doctrine of tones, in the physical and technical foundations of music, which of all arts appears to be the most immaterial, fleeting, and delicate source of incalculable and indescribable impression on our mind, that the science of the purest and most consistent though, mathematics, has proven so fruitful.'*

He studied the tones emitted by organ pipes and, for this, invented a monochromatic sound source by placing a tuning fork in a cavity-resonator, in such a way that both frequencies are mutually incommensurable, an instrument which is known as the Helmholtz's resonator.

On the combination of tones
Berl. Monatsber., Berlin, 1858

But the lack of experimental facilities at Bonn University obliged him to focus more on theory and to develop new mathematical tools. Helmholtz studied the resonance frequency of organ pipes, which was badly predicted, and he suggested that the motion of air near the mouth of the pipes cannot be neglected, as was done before by Euler, Bernoulli, Laplace and Poisson. For this he considered an inviscid fluid and, to overcome the fact there was no explicit solution of the wave equation known when one takes into account the geometry of the opening, he used Green's theorem, that he has just learned about through his friend William Thomson, and then succeeded in computing the observed resonance frequency. He also derived the equation of the velocity potential, which is known as Helmholtz' equation. He published his demonstration and results in 1858 in the Journal of Pure and Applied Mathematics under the title *'On air vibrations in pipes with open ends'*.

On air vibrations in pipes with open ends
Journal für reine und angew. Mathematik, 1858
Crelle's Mathemetical Journal, 1859

With this paper Helmholtz actually initiated a new mathematical method to solve problems when there is no known explicit solution, a method which was to play a central role in Kirchhoff's theory of diffraction and in modern scattering theory. It is important to notice the key role of William Thomson here. The original essay of George Green, who was a miller in Nottingham, had been published in 1828 at the author's expense and remained nearly unnoticed until William Thomson republished it in Crelle's Mathematical Journal in 1854, 13 years after Green's death. Helmholtz had already used Green's theorem in a paper published in 1853, where he studied electric conduction in muscles and other three-dimensional conductors.

Some laws concerning the distribution of electrical currents in conductors
Berl. Monatsber., 1852

In his next paper Helmholtz tried to explain why the pitch of organ pipes depends, not only on their length, but also on their width. He had the intuition that viscosity was playing a role here, although it is neglected in Euler's equation. He explained that his motivation was to get an *'intuition of the forms of motion that friction brings into the fluid'*. Thus, to model the internal friction of air due to its viscosity, he added a damping term to Euler's equation, while discarding its nonlinear term to simplify its resolution. Incidently it seems that Helmholtz was not aware of the fact that in France, Poisson, Navier, Saint-Venant, and Stokes in England, had already proposed to add such a term to Euler's equation. In his paper on vortex motions he explained that: *'Yet Euler has distinctly pointed out that there are cases of fluid motion in which no velocity potential exists, for instance, the rotation of a fluid about an axis where every element has the same angular velocity. Among the forces which can produce such motions, may be named friction. The effect of fluid friction has not hitherto been mathematically defined; yet it is very great and produces most marked differences between theory and fact. Hence it appeared to me to be of importance to investigate the species of motion for which there is no velocity potential'*.

Helmholtz had read *'La mécanique analytique'* de Lagrange which stated that, when an incompressible inviscid fluid is set into motion by a potential force, there exists a velocity potential which is irrotational. But, in contrast to potential forces, viscous forces are not conservative and therefore there is no velocity potential in this case. This is why Helmholtz proposed to consider twice the angular velocity instead, that he called *'vorticity'* and that he related to the effect of frictional forces. Although they cause the rotational motion, Helmholtz had the surprising and genial idea that he could neglect them anyway to make the analysis if the flow motion motion tractable analytically. Therefore, as soon as vorticity has been produced, Helmholtz neglected frictional forces and used Euler equation. Although his approach seems at first glance paradoxical, it proved to be very effective and is still commonly used today, *e.g.* vortex methods in CFD (Computational Fluid Dynamics), inviscid equations outside the boundary layers, etc... He thus studied the inviscid vorticity equation, by taking the curl of Euler's equation, which had already been studied by Lagrange in 1781 and Stokes in 1848, but the physical interpretation that Helmholtz proposed was very original.

He introduced the concept of '*vortex lines'*, which are everywhere tangent to the vorticity vector, and of *'vortex filaments'*, which contain all the vortex lines crossing a infinitely small surface element of the fluid. He then proved that vortex lines are advected by the flow. As a consequence, he deduced that vortex filaments are conserved during the flow evolution, although they can be stretched or distorted, and are either closed on themselves, as *e.g.* a vortex ring, or end at the flow boundaries. He also mentioned the *'remarkable analogy between vortex-motion of fluids and the electro-magnetic action of electric currents'* and showed that one can thus compute the angular velocity from the vorticity distribution. In the last part of the paper, he applied these theorems to study several types of motion: a plane vortex sheet in an infinite domain, two rectilinear vortex tubes, and two vortex rings, for which he explained how they pass alternately through each other. He also suggested to the reader a simple experiment to produce and observe vortex rings, for which one needs only a spoon and a quiescent water surface. Note that this production of new vortices do not contradict his previous theorem since in this case the introduction of the spoon from the boundary has modified the flow topology which thus created a vortex dipole. He published his work in 1858 in the Journal of Pure and Applied Mathematics under the title *'On integrals of hydrodynamic equations which correspond to vortex motions'*.

> *On integrals of hydrodynamic equations which correspond to vortex motions*
> *Journal für reine und angew. Mathematik, 55, 25-55 (1858)*
> *Phil. Magazine and Journal of Science, 33, 485-512 (1867),*
> *translated by Tait*

This masterpiece of fluid mechanics combines analytical equations and geometrical representations, in a style which is very similar to what British scientists were doing at that time. For instance, William Thomson was using the analogy between continuum mechanics and electromagnetism and deduced from it the concept of *'solenoidal'* magnetic field in 1849. He was followed by his British colleagues: Stokes introduced in 1849 in his memoir on diffraction the decomposition of a vector field into rotational and potential components, Faraday the concept of *'lines of forces'* and Maxwell the concept of *'tubes of force'* in 1855. Helmholtz was inspired by British physicists, since he was corresponding with some of them, *e.g.* Thomson and Tait, although he did not refer to their works in his paper. Actually he used the same analogy as they did, but the other way round, *i.e.* he got insight into fluid mechanics from his knowledge of electromagnetism, acquired while he was studying the physiology of nervous impulse. In particular, he recognized that Biot-Savart's law, which gives the electric current induced by a magnetic field, reconstructs likewise the velocity field from a given vorticity field.

His British colleagues received Helmholtz' work with enthusiasm. Tait built a smoke box to produce vortex rings and published an English translation of his paper. Maxwell proposed hexagonal three-dimensional vortices as the mechanical model underlying his laws of electromagnetism published in 1861. Six years after, Thomson in his famous memoir 'On vortex atoms' extensively used Helmholtz's work. In this paper Thomson derived Stokes' theorem (which should bare his name), then Kelvin's theorem (baring his own new name as a Lord), which states the conservation of circulation, and also studied the kinematics of knotted vortex rings that he proposed as model of atoms. Both

Helmholtz and Kelvin's theorems are the corner stones of vortex theory. They inspired the last attempt of British physicists, pioneered by ancient philosophers such as Democrite and Lucretius, and later Descartes, to use vortices as the building blocks of micro and macro cosmos. Unfortunately those theories failed due to the generic instability of vortex rings. But this tremendous effort made at the end of the 19th century to understand vortex dynamics is still very useful to modern fluid dynamics, to analyze turbulent flows and compute their evolution using vortex methods. Helmholtz and Kelvin are the pioneers of the turbulence theory, which is not yet unified and is still a challenge for modern physics.

In the 19th century, scientists studied fluid mechanics were split into two groups, whose methods and concepts were quite incompatible: engineers interested in hydraulics and physicists focusing instead on hydrodynamics. Helmholtz and Kelvin were among the few who were able to understand both approaches and work towards a unified theory. Starting from a very applied problem: trying to understand the acoustic emission of organ pipes and how a steady air flow can produce periodic oscillations. He thus studied the air motion in an organ pipe, taking onto account the detailed motion near the opening of the tube. He first devised an inviscid theory to predict the frequency of the emitted sound and then, in a memoir published in 1963, he took also into account the role of viscosity whose effect is to broaden and shift in frequency the resonance of the organ pipe.

Starting with the problem of predicting the sound of organ pipes, he made the hypothesis of the presence of air layers which slide over each others, thus presenting a velocity jump at their interface near the mouth of the pipe. He then showed that these surfaces of discontinuity, called mixing layers, are singular sheets of vorticity which are solutions of Euler equations and subjected to an inviscid nonlinear instability. In his memoir on *'The discontinuous motions of fluids'*, published in 1868, he explained that: *'I have described the mechanical peculiarities of such motions, and deduced from the theory how they are brought about by means of the blade-shaped current of air at the mouth of an organ pipe which is blown. The bounding surfaces of this current, which cuts through and across the mass of air runs into and out of the mouth of the pipe, are to be considered as vortical surfaces, that is, surfaces which are faced with continuous stratum of vortical filaments or thread-like eddies. Such surfaces have a very unstable equilibrium.[…] This resolution into vortices takes place in the blade of air at the mouth of the pipe, where it strikes against the lip. From this place on, it is resolved into vortices, and thus mixes with the surrounding oscillating air of pipes, and accordingly as it streams inwards and outwards, it reinforce its inward or outward velocity, and hence acts as an accelerating force with a periodically alternating direction, which turns from one side to the other with great rapidity. […] During the phase of entrance of air, the blade is*

also directed inwards, and thus on its part reinforces the 'vis viva' of the inward currents. Conversely, for the outward current. If we suppose the accelerating force of the current of air to be represented by one of Fourier's series, the amplitude of any term of the order m will in general diminish as 1-m.' This is known today as the Kelvin-Helmholtz instability: a perturbation of frequency f causes the mixing layer to roll up into discrete vortices, exciting higher and higher harmonics (2f, 3f, …) with smaller amplitudes. This is followed by the pairing process in which two adjacent same sign vortices spin around each other and then merge. Such coalescence resulted in the appearance of subharmonics (f/2, f/3, …). Successive pairings occur up to the moment where a three-dimensional secondary instability begins to develop and thus affects the pairing process.

Still struggling for predicting the sound of organ pipes, Helmholtz made the hypothesis of the presence of air layers which slide over each others, thus presenting a velocity jump at their interface near the mouth of the pipe. He then showed that these surfaces of discontinuity, called mixing layers, are singular sheets of vorticity which are solutions of Euler equations and subjected to an inviscid nonlinear instability. In his memoir on *'The discontinuous motions of fluids'*, published in **1868**, he explained that: *'I have described the mechanical peculiarities of such motions, and deduced from the theory how they are brought about by means of the blade-shaped current of air at the mouth of an organ pipe which is blown. The bounding surfaces of this current, which cuts through and across the mass of air runs into and out of the mouth of the pipe, are to be considered as vortical surfaces, that is, surfaces which are faced with continuous stratum of vortical filaments or thread-like eddies. Such surfaces have a very unstable equilibrium.[…] This resolution into vortices takes place in the blade of air at the mouth of the pipe, where it strikes against the lip. From this place on, it is resolved into vortices, and thus mixes with the surrounding oscillating air of pipes, and accordingly as it streams inwards and outwards, it reinforce its inward or outward velocity, and hence acts as an accelerating force with a periodically alternating direction, which turns from one side to the other with great rapidity. […] During the phase of entrance of air, the blade is also directed inwards, and thus on its part reinforces the 'vis viva' of the inward currents. Conversely, for the outward current. If we suppose the accelerating force of the current of air to be represented by one of Fourier's series, the amplitude of any term of the order m will in general diminish as 1-m.'* This is known today as the **Kelvin-Helmholtz instability**: a perturbation of frequency f causes the mixing layer to roll up into discrete vortices, exciting higher and higher harmonics (2f, 3f, …) with smaller amplitudes. This is followed by the pairing process in which two adjacent same sign vortices spin around each other and then merge. Such coalescence resulted in the appearance of subharmonics (f/2, f/3, …). Successive pairings occur up to the moment where a three-dimensional secondary instability begins to develop and thus impairs the pairing process. Several years later, while in Berlin, Helmholtz used the same idea to explain **turbulent mixing in the atmosphere**, since he proved that discontinuous boundaries between stratified air layers could become nonlinearly unstable. In his paper published in **1888**, he explained: *'The principle obstacle to the circulation of our atmosphere, which prevents the development of far more violent winds than are actually experienced, is to be found not so much in the friction on the earth's surface as in the mixing of differently moving strata of air by means of whirls that originate in the unrolling of surfaces of discontinuity. In the interior of such swirls the originally separate strata of air are wound in continually more numerous and therefore thinner layers spiralling about each other; the enormously extended surfaces of contact allow a more rapid exchange of temperature and the equalization of their movement by friction'*. This was later confirmed by experimental measures performed on meteorological balloons. He proposed the same mechanism for the formation of waves under the action of the wind. Helmholtz has made several important contribution in meteorology before: in **1865** he explained the origin of the **foehn wind** using thermodynamics, which was new in this field. He was also interested by the general circulation of atmospheric motions, discussing the sensitivity to initial conditions and the subsequent difficulty of predicting atmospheric motions, which he stated in very modern terms in a lecture on *'Cyclones and thunderstorms'* he gave in 1876: *'The only natural phenomena that we can pre-calculate and understand in all their observable details, are those for which small errors in the input of the calculation bring only small errors in the final result. As soon as unstable equilibrium interferes, this condition is no longer met. Hence chance still exists in our horizon; but in reality chance only is a way of expressing the defective character of our knowledge and the roughness of our combining power'*. He also proposed an explanation of the equatorial calms, predicted similar effects around the poles and conjectured that the mid-latitude perturbations are due to the encounter of equatorial and polar air, idea which was then developed by the Norvegian meteorologist Vilhem Bjerknes with his theory of the 'polar front'.

In conclusion, Helmholtz was like the great creators of the Renaissance period, as *e.g.* Leonardo, a universal genius able to distillate the essential features from very diverse phenomena, to perceive the unity hidden behind observations as diverse as organ sound emission and cloud formation. His broad band culture, ranging from surgery, anatomy, physiology, psychology, to physics, mathematics, epistemology, his combination of experimental and theoretical approaches, and his talent as science manager, show how exceptional Helmholtz was. It is also very impressive to realize that in all the fields he has been studied, his discoveries are still in use and are considered as very modern. Let him concludes :*'I have been able to solve a few problems of mathematical physics on which the greatest mathematicians since Euler have struggles in* *vain… But the pride I could have felt over the final results… was considerably diminished by the fact that I knew well how the solutions had almost always come to me: by gradual generalizations of favourable examples, through a succession of felicitous ideas after many false trails. I should compare myself to a mountain climber who, without knowing the way, hikes up slowly and laboriously, often must return because he cannot go further, then, by reflection or by chance, discovers new trails that take him a little further, and who, when he finally reaches his aim, to his shame discovers a royal road on which he could have trodden up if he had been clever enough to find the right beginning. Naturally, in my publications I have not told the reader about the false trails and I have only described the smooth road by which he can now reach the summit without any effort'* (Hermann von Helmholtz, 1891).

PORTRAITS

Statue of Hermann Helmholtz
In front the Humbolt University, Unter den Linden, Berlin
(Photo: Kai Schneider)

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