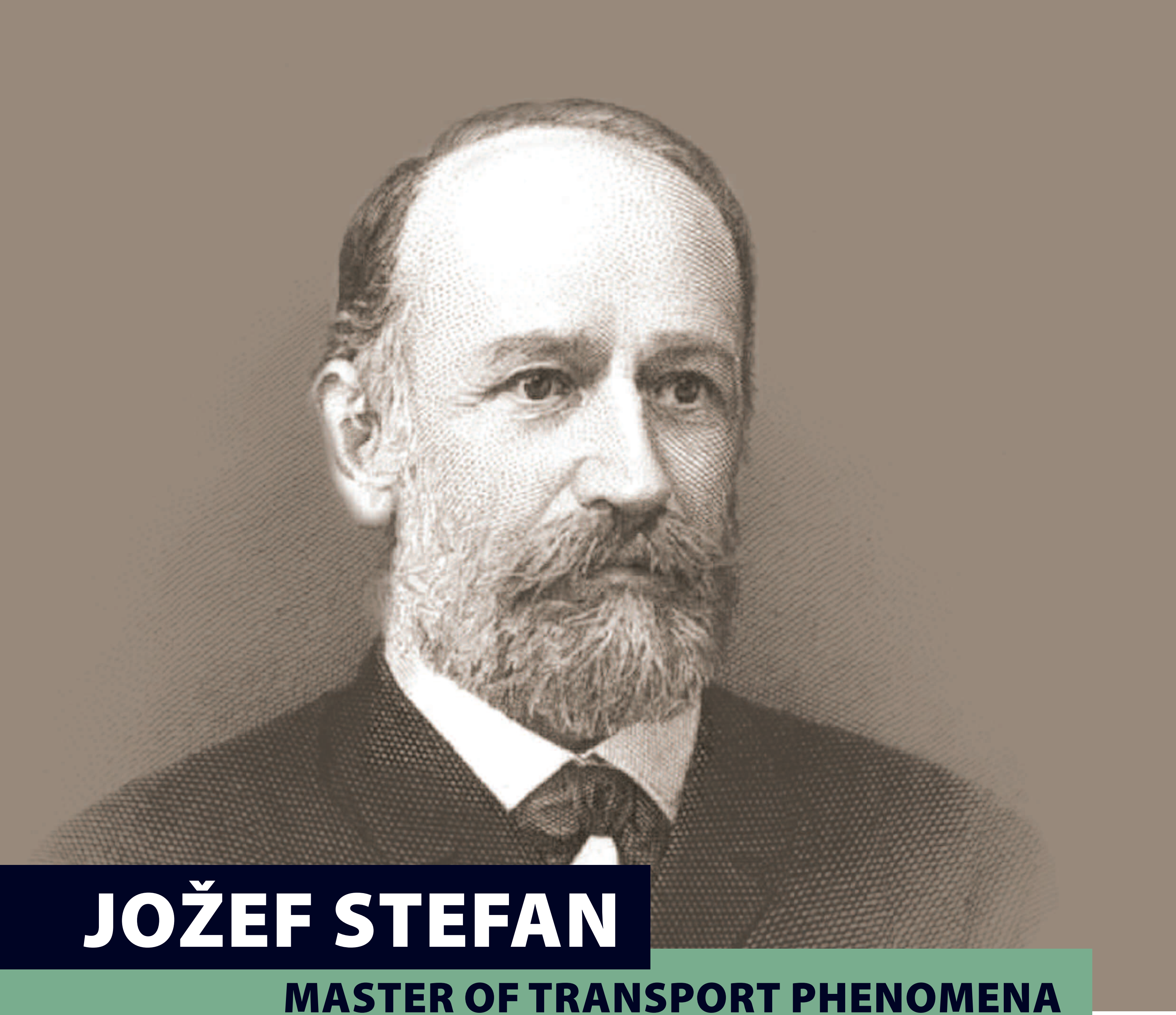


JOŽEF STEFAN

MASTER OF TRANSPORT PHENOMENA

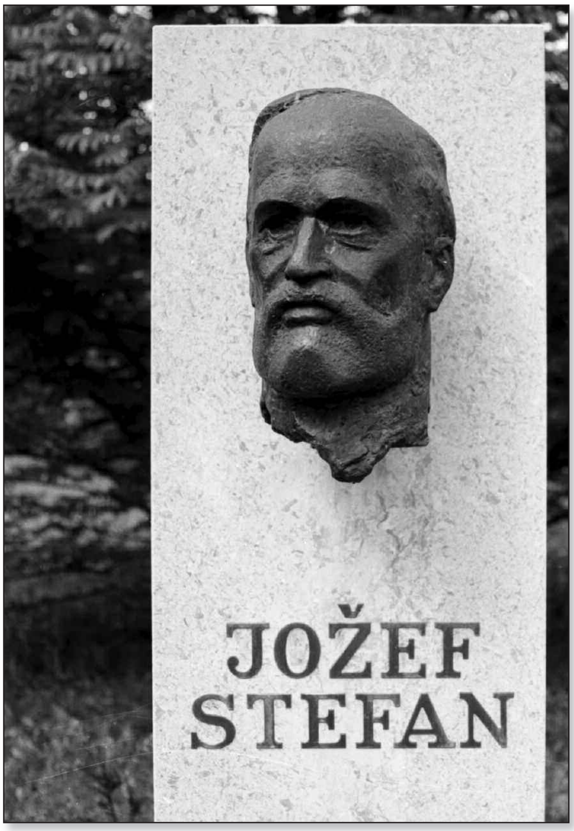
■ J. Strnad – Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenija – DOI: 10.1051/epn/2011201

Jožef Stefan is famous primarily for the Stefan-Boltzmann radiation law. But this remarkable physicist made original contributions in all fields of physics: fluid flow, mechanical oscillations, polarization of light, double refraction, interference and wavelength measurements. He also measured the heat conductivity of gases. He was among the few physicists who promoted Maxwell's electrodynamics theory.

In Stefan's life there are two distinct periods. During the first Stefan followed many interests including literature, whilst the second was devoted entirely to physics. Stefan was a Slovenian who achieved his scientific successes in Vienna as a citizen of Austria (after 1867 Austria-Hungary).

Jožef Stefan (Fig. 1) was born on March 24, 1835 at St. Peter, nowadays part of Celovec (Klagenfurt) [1]-[5]. His teachers soon noticed his talents. In 1845 he entered the gymnasium and in 1853 he went to the University of Vienna to study mathematics and physics. In his youth he loved to sing and took part in choirs which he also organized. Under the tutorship of his teacher and together with his schoolmates he founded a hand-written Slovenian literary journal. He wrote poems for it, which were later published in Slovenian journals appearing in Austria. He did not overestimate the value of his poems, but he could well have become a Slovenian poet had he not chosen ►

▲ Jožef Stefan (1835-1893)



▶ FIG. 1: Jožef Stefan (March 24, 1835 – January 7, 1893). Bust in front of the J. Stefan Institute in Ljubljana

> **This humble, hard-working scientist made a permanent impact on the field of heat transfer. It is remarkable that a single figure, about whom so little is known, could make such important contributions to conduction, convection and radiation heat transfer.**
>
> **J. Crepeau [4]**

otherwise. In these journals he published also articles referring to a broad range of subjects from mathematics and physics to literature and society. After 1859 he did not publish any more texts in Slovenian. This was probably due to his growing involvement in physics.

In 1857 Stefan passed the teacher's examination. On his own initiative he began research in theoretical physics and sent a paper to the Academy of Science. There he held a lecture which raised the interest of Karl Ludwig, a well-known professor of physiology. Stefan accepted his invitation to collaborate in experimental work at the Institute of Physiology, as a position at the Institute of Physics did not seem within reach.

In 1858 Stefan passed the philosophical *rigorosum* at the university and obtained his PhD. In 1860 he was elected a corresponding member of the Academy. Nevertheless, the possibility for him to do experimental work at the Institute of Physics seemed very remote.

However, the situation changed in 1863. Aged 28, he became the youngest full professor in the country. He also obtained a position at the Institute of Physics and in 1865 he became its Director. He was elected a full member of the Academy of Science, and for one of his publications he was awarded the Lieben prize. At that point, all Stefan's wishes regarding his scientific carrier were accomplished.

As he dedicated himself to work, he shut himself off from the outside world. Apparently, he often did not leave the Institute staying there for days. Only after 1891, when he married a widow, it seemed that at last he relaxed and regained his cheerfulness. At the end of 1892 he had an apoplectic stroke and died on January 7, 1893.

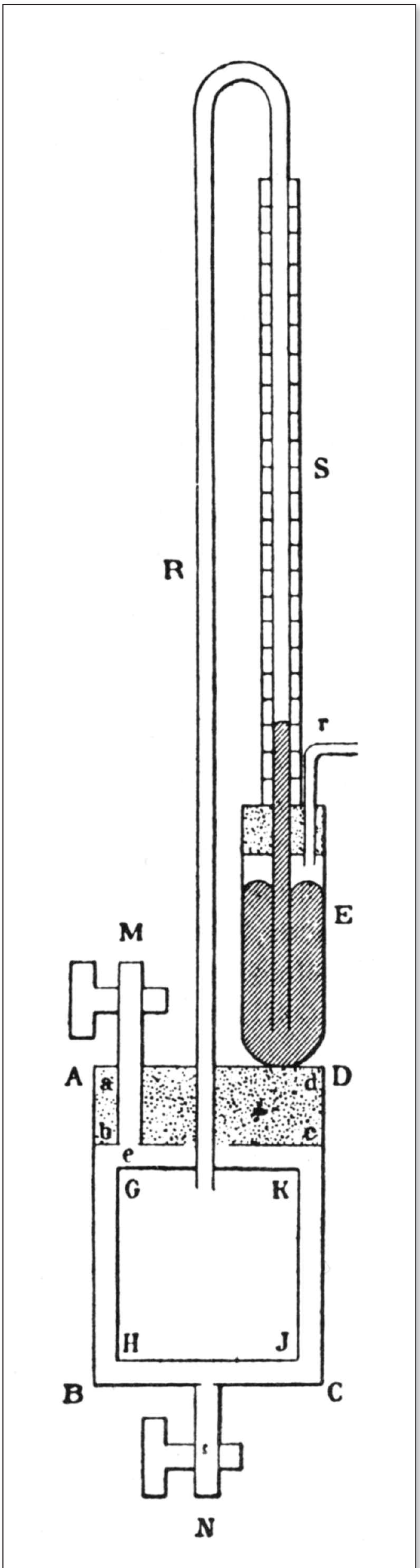
Heat conduction in gases

At the time there were doubts whether heat conduction in gases could be measured at all. After some trials in 1872, Stefan invented the "diathermometer" (Fig. 2) [6], consisting of a cylinder made of thin copper or brass sheet surrounded by a larger cylinder. The small gap between the two cylinders was filled with the gas under investigation. The temperature of the outer cylinder was controlled by a mixture of ice and water. The gas in the inner cylinder, initially at room temperature, cooled down through heat conduction across the gas-filled gap. This caused the pressure in the inner cylinder, measured by a mercury manometer, to reduce. The rate of pressure change yielded the heat conductivity of the gas in the gap. This gap was sufficiently narrow for convection not to develop. A reduction of the gas pressure inside the gap to about half the normal air pressure did not alter the result. This was in agreement with Maxwell's prediction that the thermal conductivity of gases is independent of pressure. In 1875 Stefan compared the conductivities of a number of gases [6] and obtained the values 0.0234 W/(K.m) for air and 0.188 W/(K.m) for hydrogen, the current values being 0.0241 W/(K.m) and 0.168 W/(K.m), respectively.

Stefan's radiation law

At the time, the radiation of heat was described by an equation derived by Pierre Louis Dulong and Alexis Thérese Petit. This derivation rested on observing the cooling rate of a large mercury thermometer bulb placed inside an even larger spherical vessel. The vessel was evacuated to a pressure of some millibars, such as to eliminate the influence of convection and conduction. Stefan realised that conduction still played a significant role and set out to find a better way to describe thermal radiation [7].

In 1864 John Tyndall investigated "obscure radiation", now known as infrared light, by electrically heating a platinum wire. In the part of the spectrum beyond the red he fixed a thermopile and measured the current as a



◀ **FIG. 2:** Stefan's diathermometer [6]. ABCD: hollow copper cylinder; abcd: small copper vessel filled with cork; GHKJ: smaller hollow copper cylinder; r: small tube for adjusting the initial reading of the mercury manometer SE.

function of the colour of the wire. Among his numerous data, one stated that the wire at `full white heat' radiates 11,7-times more energy than 'at faint red heat'. Adolph Wüllner included Tyndall's data in a new edition of his physics textbook, attributing to 'faint red heat' a temperature of 525 °C and to 'full white heat' a temperature of 1200 °C. Stefan used these data in 1879, transforming them to absolute temperature and observing that by raising the ratio 1473/798 = 1,85 to the fourth power it equalled 11.6. His bold conclusion was that the heat radiated is proportional to the fourth power of the absolute temperature: $j = \sigma T^4$. Here j is the energy density flow emitted by a black body at absolute temperature T. He also estimated the proportionality coefficient, the Stefan constant σ, to be $4.5{\cdot}10^{8}\,\mathrm{W/(m^2K^4)}$ compared with the current value of $5.67{\cdot}10^{-8}\,\mathrm{W/(m^2K^4)}$. For the surface temperature of the sun he obtained the first reasonable value of about 5500 °C.

Stefan was a bit lucky. Tyndall's measurement referred to infrared light and not to the radiation at all wavelengths contained in Stefan's law. Furthermore, for a platinum wire the law does not apply since its emissivity is not unity, and Wüllner's temperatures were chosen somewhat arbitrarily.

In 1884 Ludwig Boltzmann, a former student of Stefan's, deduced the law by studying an ideal thermal engine working with radiation. This law is now known as the *Stefan-Boltzmann law*. Today, Stefan's law and the Stefan constant derive from Planck's law, which launched the start of quantum physics in 1900.

Diffusion and evaporation

In the kinetic theory of gases, Stefan considered the motion of molecules in gas mixtures [8]. He studied collisions of molecules and their rates as well as the changes of velocities and discussed equations that were partially derived by Maxwell. He independently discovered the Maxwell-Stefan or Stefan-Maxwell diffusion theory which stands as a model for diffusion in multicomponent systems [9].

Evaporation of water is important for meteorologists. Stefan chose to carry out experiments with ether vapour instead. He contained ether in a vertical tube and, by observing the speed at which the surface of the liquid ▶

“Stefan published in total 83 papers, almost without exception in the Proceedings of the Vienna Academy of Science. Some 13 were subsequently published in Poggendorffs and 10 later on in Wiedemanns Annalen der Physik und Chemie. A few were reported in The Philosophical Magazine [2,3].”

▲ **FIG. 3:** The J. Stefan Institute in Ljubljana. Thanks are due to Marjan Smerke and Marjan Verč for the preparation of figures.

▶ lowered, he came to some conclusions which nowadays are described by the diffusion law. He also measured the diffusion constant of ether vapour in air [10]. In Stefan´s experiment the air does not move while the vapour does. Thus, a macroscopic motion of the vapour, expressed by the quantity $\rho_v v$, with ρ_v the partial density of the vapour and v the centre-of-mass velocity of the mixture, is derived, known as the *Stefan flow* by contemporary meteorologists. In clouds, this represents the flow of water vapour towards growing water droplets, carrying with it aerosol particles, thereby cleansing the surrounding air. Of course, the situation in a cloud is complicated by geometry and heat released at condensation [11].

Stefan's problem

Stefan also considered heat flow in a phase change. The surface of a layer of water at temperature $T_0 = 0$ °C is brought into contact with a heat reservoir at temperature $T < T_0$. A layer of ice will now form on the water at T_0. The thickness of the ice layer and its temperature profile are to be determined. Based on the problem of heat conduction in a layer without phase change Stefan found a solution in closed form, thus solving a "problem with a moving boundary". Today this is called the *Stefan problem*.

Electrodynamics

Stefan also studied Maxwell's electrodynamics and obtained valuable results concerning the basic equations, the induction law, magnetic and electric forces, the force of electromagnets, thermo-magnetic motors, the inductivity of coils. Being appointed chairman of the scientific committee of the electrical world exhibition in Vienna 1883 he contributed six papers to the *Proceedings* in 1886, in which he considered the measurement of characteristic quantities of electric generators. He was elected the first chairman of the Austrian Society of Electrical Engineering and editor-in-chief of its publications.

Stefan was a devoted lecturer. He was extremely active, as a provisional list of his duties around 1883 shows: Vice-Chairman of the Academy of Science and secretary of its scientific-mathematical class, Rector of the Vienna University, Dean of the Faculty of Philosophy, member of the faculty board, Director of the Institute of Physics, a member of the committee on explosions of mining gases. In 1885, he was appointed chairman on the international committee defining the international normal tone. He received Austrian and international honours. He is also considered founder of the Vienna school of physics. In Ljubljana a great research institute bears his name (Fig. 3). ■

“ The Stefan number S_{te} is defined in phase-change processes as the ratio between sensible heat and latent heat: $S_{te} = c_p T/L$ with c_p specific heat at constant pressure, L latent heat, T temperature difference between phases. ”

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