The Erwin Schrödinger International Institute for Mathematical Physics

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ESI NEWS

Volume 4, Issue 2, Autumn 2009

Contents

Editorial

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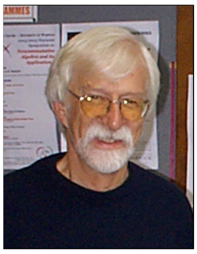


The scientific activities of the ESI during the second half of 2009 spanned as usual a wide range of topics, with thematic programmes devoted to *Entanglement and Correlations in Many-body Quantum Mechanics* (organized by B. Nachtergaele, F. Verstraete and R. Werner), *Classical and Quantum Aspects of Cosmology* (P.C. Aichelburg, H. Rumpf), *Recent Advances in Integrable Systems of Hydrodynamic Type* (A. Constantin, J. Escher) and *The $\bar{\partial}$-Neumann Problem: Analysis, Geometry and Potential Theory* (F. Haslinger, B. Lamel, E. Straube). These programmes were accompanied and complemented by workshops on Mathematical Biology (*Architecture and Evolution of Genetic Systems*, organized by R. Bürger, A.G. Jones and S.J. Arnold), on *Quanta and Geometry* (organized by A. Carey, J. Schwermer and J.Yngvason) and *Quantum Computation and Quantum Spin Systems* (as part of the programme on many-body quantum mechanics).

In addition to this (incomplete) list of activities at the ESI focused on current research, several smaller events devoted to history of science took place at the Institute, among them the closing workshop *Kontexte* of the Vienna University *Initiativkolleg on Sciences in Historical Context* led by M. Ash. This Intitiativkolleg will be followed by a 'DK+' (a FWF-funded doctoral programme starting in 2010) on *The Sciences in historical, philosophical and cultural contexts* with participation by the ESI.

The Institute's activities were rounded off by *Senior Research Fellows Lecture Courses* on *L^2-Methods in Complex Analysis* (J. McNeal) and *Supergravity Theories* (P. West), and by the *ESI Junior Research Fellows' Programme*, to which the contribution by M.A. Jivulescu in this issue is devoted.

Although the scientific performance of the ESI in 2009 was very successful by any standard, the funding situation of the Institute remains uncertain in view of a complete absence of longer term financial commitment by the Austrian Federal Ministry for Science and Research. The Junior Research Fellows Programme remains under threat in spite of its reprieve for 2010, and the Institute has not yet received any response whatsoever to the recommendations in the Institute's Evaluation Report of June 2008 (to remind the reader: the Institute was evaluated in April 2008 by a panel consisting Peter Goddard (chair), Jean-Michel Bismut, Robbert Dijkgraaf, Felix Otto and Scott Sheffield). Maintaining a scientific planning horizon of 2 – 3 years in this situation of financial uncertainty requires a degree of reckless optimism which is not always easy to justify and maintain.

These somewhat sombre thoughts should not, however, distract us from the season's festive spirit, and I will conclude this editorial by conveying to all readers of this newsletter and all friends and guests of the ESI warmest Season's Greetings and best wishes for 2010!

The critical temperature of dilute Bose gases

Robert Seiringer

Bose-Einstein condensation (BEC) is a subtle phenomenon occurring in gases of a certain kind of particles – bosons – at very low temperatures. Its occurrence was predicted in the mid-1920s by Einstein [1], even before the formulation of quantum mechanics. His work was based on a previous paper by Bose [2] who applied what is now called Bose-Einstein statistics to quanta of the electromagnetic field. The phenomenon had to wait until 1995 for experimental verification in cold atomic gases, however. Decades of progress in the trapping and cooling of atoms have led to these remarkable experiments, whose pioneers were awarded the Nobel prize in physics in 2001. Since then, literally thousands of research papers have been written both by theorists and experimentalists exploring the fascinating behavior of Bose-Einstein condensates.

The mathematical derivation of BEC was done by Einstein under the assumption that the particles that make up the gas do not interact at all. This assumption is justified to a certain degree for gases at very low density, but is clearly an approximation whose effect remains to be investigated. To this date, however, no rigorous derivation of BEC for interacting systems is available. It remains one of the most fascinating open problems in mathematical physics. In particular, most theoretical predictions on the behavior of many-body systems at low temperatures are based on more or less intuitive assumptions and various approximation schemes. A notable exception concerns a toy model describing hard spheres hopping on a lattice, at exactly half filling, i.e., with half as many particles as there are lattice sites. This is the only model for which a rigorous proof of the existence of BEC in the thermodynamic limit is available [3].

Sometimes different approximation schemes lead to different answers to physically relevant questions. One such question concerns the critical temperature for the occurrence of BEC, and its dependence on the interactions among the particles. To be precise, it is expected that there exists a critical temperature, $T_c(\varrho)$, depending on the particle density ϱ, such that the one-particle reduced density matrix, $\langle a^\dagger(x)a(y)\rangle$, in a thermal equilibrium state decays exponentially as $|x-y|\to\infty$ if the temperature T exceeds $T_c(\varrho)$ but converges to a finite, non-zero value for $T<T_c(\varrho)$. In the latter case, this non-zero value equals the density of the Bose-Einstein condensate. For non-interacting bosons, $T_c(\varrho)$ can be calculated explicitly. For a three-dimensional gas of bosons of mass m, it is given by

$$T_c(\varrho)=T_c^{(0)}(\varrho)=\frac{\hbar^2}{mk}\frac{2\pi}{\zeta(\frac{3}{2})^{2/3}}\varrho^{2/3} \quad (1)$$

where ζ denotes the Riemann zeta function, $\hbar$ denotes Planck's constant (divided by 2π) and k is Boltzmann's constant.

The introduction of interactions among the particles will certainly alter this critical temperature, and (1) can not be expected to be strictly valid for realistic systems. Contradictory statements can be found in the physics literature concerning the dependence of $T_c(\varrho)$ on the interactions, and both the magnitude and the sign of the interaction-induced change have been disputed. The earliest statement concerning this question is probably due to Feynman [4] in 1953 who argued that interactions would lead to an increased effective mass of the particles and hence should decrease the critical temperature. Feynman was not concerned with dilute gases, of course, but his main interest was liquid helium for which the critical temperature for superfluidity is indeed roughly a factor 1.5 smaller than (1).

For dilute gases recent numerical studies, based on quantum Monte Carlo simulations, predict that the critical temperature should *increase*, in fact, at least as long as the particle interactions are repulsive. They predict a shift in the critical temperature of the form

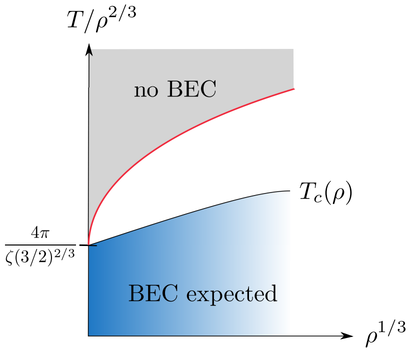
$$\frac{\Delta T_c}{T_c^{(0)}}=\frac{T_c-T_c^{(0)}}{T_c^{(0)}}\approx c\,a\varrho^{1/3} \quad (2)$$

where $c\approx 1.3$ is a universal constant and a denotes the scattering length of the interaction potential. This formula is supposed to be valid in the dilute regime, i.e., when $a\varrho^{1/3}\ll 1$. While (2) seems to represent the current consensus among researchers in the field, physicists have come to widely diverging conclusions in the past, however, both about the *sign* of c and its numerical value, as well as the power of the small parameter $a\varrho^{1/3}$. As mentioned above, Feynman's intuitive argument leads one to conclude that T_c *decreases*. Other authors in the 70's and 80's also predicted a negative ΔT_c, while yet others, beginning in 1958, claimed a positive ΔT_c proportional to $(a\varrho^{1/3})^{1/2}$, $a\varrho^{1/3}$ or $(a\varrho^{1/3})^{3/2}$ with different values of c, respectively. We refer to [5, 6] for an extensive list of references on the subject. The only experimental investigation on the subject seems to confirm (2) for a value of $c\approx 5$; it was later pointed out that the estimate of the scattering length between particles in this experiment was not correct, however.

The various differing predictions concerning the shift in the critical temperature for BEC due to interactions indicate that this is a very subtle problem for which both intuition and otherwise well-established approximation techniques fail. Where physical intuition fails only rigorous mathematics can lead to unambiguous answers. Unfortunately, lower bounds on the critical temperature for BEC seem to be out of reach of present day methods. Rigorous upper bounds can be derived, however, as it turns out. In fact, in a recent joint work with D. Ueltschi [6], it was shown that

$$\frac{\Delta T_c}{T_c^{(0)}}\leq 5.1\sqrt{a\varrho^{1/3}} \quad (3)$$

for small $a\varrho^{1/3}$ and for arbitrary repulsive interaction potentials with scattering length a. In other words, in the presence of only repulsive interactions among the bosons the critical temperature can not increase, compared to the value for non-interacting particles, by more than the square root of the ratio of the scattering length to the mean particle distance. Although this bound does not reproduce the linear behavior expected from numerical simulations, it is the first and, so far, only mathematically rigorous result concerning the critical temperature for BEC of interacting particles.



The red line shows the rigorous upper bound on the critical temperature for BEC. The dashed line corresponds to the expected behavior based on numerical simulations. Units are chosen such that $\hbar = 2m = k = 1$.

The proof of (3) in [6] uses in an essential way the functional integral representation of the correlation functions in terms of paths of Brownian loops, which results from the use of the Feynman-Kac formula together with a representation of permutations in terms of cycles [7]. As pointed out in [8], it follows quite easily from this representation that at a fixed chemical potential, as opposed to a fixed density, correlation functions are monotone in the interaction and hence only decrease when repulsive interactions are switched on. In particular, exponential decay of the one-particle density matrix $\langle a^\dagger(x)a(y)\rangle$ for the interacting system follows from exponential decay of the corresponding quantity for the non-interacting Bose gas at the same chemical potential. From the explicit solution of the non-interacting Bose gas one thus knows that exponential decay holds as long as the chemical potential is strictly negative, and this gives an upper bound on the critical temperature. What remains to be understood is the consequence of the negativity of the chemical potential on the particle density.

At fixed chemical potential, repulsive interactions decrease the density, and the main result in [6] is a bound on how much the density decreases. Using the functional integral representation, as well as a novel variational principle for integrals over differences of heat kernels (with and without interaction potential, respectively), one obtains a lower bound on the particle density in terms of the one for non-interacting particles minus terms involving the scattering length of the interaction potential. In this way one obtains the upper bound (3) on the critical temperature.

Besides the question of the value of the critical temperature, there are many other interesting questions about Bose-Einstein condensates, most of which are widely open from a mathematical physics point of view. For a sample of topics of interest, we recommend the recent review [9]. A collection of recent rigorous results can be found in [10]. There remains lots to be understood about the subtle quantum mechanical effects in many-body systems at ultra-low temperatures.

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A philatelic introduction to the Doppler effect and some of its applications

Oskar Maria Baksalary and George P. H. Styan

Christian Andreas Doppler (1803–1853), 150th anniversary of the Doppler effect (1842): Austria 1992, *Scott*[1] 1563.

The Austrian mathematician and physicist Christian Andreas Doppler (1803–1853) is most famous for his principle, now known as the Doppler effect. The Doppler effect is that the observed frequency of a wave depends on the relative speed of the source and the observer. The received frequency is higher (compared to the emitted frequency) during the approach, is identical at the instant of passing by, and is lower during the recession.

Our purpose in this article is to present an introduction to the Doppler effect and some of its applications illustrated with postage stamps, following our article [66] in the last issue of *ESI-News*. The stamp featuring Doppler shown above was issued in 1992 by Austria on the occasion of the 150th anniversary of the Doppler effect (1842) and was also included in two short articles, respectively by Catalano [12] and by Pai-Dhungat & Falguni [58][2]; see also [37, p. 153, #48].

Our article ends with a bibliography of about 100 items. For information about Doppler and the Doppler effect we found the books by Aaslid [1], Hiebl & Musso [38], Schuster [76], Štoll [86] to be very helpful. For more about stamps in physics: see Reinhardt [67] and Weber [97], mathematics: Männikkö [51], Miller [55], and Wilson [101], chemistry: Heilbronner & Miller [37], and science in general: Schaaf [72].

Doppler's theoretical work on the effect was published in German [17] in 1842/1843 under the title "Ueber das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels: Versuch einer das Bradley'sche Aberrations-Theorem als integrirenden Theil in sich schliessenden allgemeinen Theorie" (English translation [25, p. 101]: "On the coloured light of the double stars and some other stars of the heavens: an attempt at a general theory which includes Bradley's Theorem of Aberration as an integral part").

James Bradley (1693–1762), with Greenwich Observatory and (top right) Nicolaus Copernicus (1473–1543): Nicaragua 1994, *Scott* 1984f.

Ole Christensen Rømer (1644–1710), 300th birth anniversary: Denmark 1944, *Scott* 293.

The title indicates that Doppler's principal aim was to account for the colours and magnitudes of double star components and of variable stars, since he believed that both are influenced by stellar motion in the line of light. Doppler claimed that his principle was a generalization of Bradley's aberration theorem, due to the English astronomer James Bradley (1693–1762); this theorem pertains to an apparent displacement of the position of stars in the sky.

Bradley is best known for two fundamental discoveries in astronomy: the aberration of light, and the nutation of the Earth's axis. The discovery of the aberration of light provided conclusive evidence for the movement of the Earth. The theory of aberration also gave Bradley the means to improve on the accuracy of the previous estimate of the speed of light, which had already been shown to be finite by the work of a Danish astronomer Ole Christensen Rømer (1644–1710), who in 1676 made the first quantitative measurements of the speed of light.

Angel with trumpet, St. Cecilia Cathedral, Albi: France 2009, *Scott* 3597.

"Locomotive of 1835": Belgium 1949, *Scott* Q310.

As early as 1845, experiments were conducted by Christophorus Henricus Diedericus Buys Ballot (1817–1890) with musicians on railway trains playing instruments and other trained musicians writing down the apparent note as the train approached them and receded from them. The experiment confirmed that the sound's pitch was higher than the emitted frequency when the sound source approached, and lower than the emitted frequency when the sound source receded. Buys Ballot first published his results in the Dutch musical journal *Caecilia* [8, 9] in 1845 (see also [7, 10, 11, 29] and stated that the musical instruments used were the *signaalhoorn* (bugle[3]) and the *klephoorn* (keyed bugle [20, pp. 7, 43], [34, p. 22, #158], Ventiltrompete [10]). The locomotive he used

[1] *Scott* catalog numbers are as given in the *Scott Standard Postage Stamp Catalogue* [82].

[2] Pai-Dhungat & Falguni [58] also included a stamp (*Scott* 965) from Fiji issued in 2002 (not 1900 as stated there) showing an echocardiogram being administered by a technician on the Operation Open Heart visit to Fiji.

[3] The earliest trumpets were signaling instruments used for military or religious purposes [100], rather than for concert music, and the later bugle continued this signaling tradition with use by postal services and railways, and as such we believe would have made one readily available for Buys Ballot's experiment.

was apparently purchased by the Dutch railway from Belgium [92] and the experiments were conducted at the Marrssen railway station [79] just outside Utrecht.

Buys Ballot is best known for his accomplishments in the field of meteorology, specifically for the explanation of the direction of air flow in large weather systems. Buys Ballot also founded the Royal Dutch Meteorological Institute in 1854 and he remained its chief director until his death. In addition, the periodogram [73], which is an estimate of the spectral density of a signal, is based on periodic tables first constructed by Buys Ballot [3, pp. 106–107, 112], [56, pp. 354–360].

Doppler in his seminal paper [17] considered both sound and light waves, the latter particularly with respect to starlight. Although changes in frequency of light waves were impossible to observe using the instruments of the time, the situation with sound was rather different. Doppler made two incorrect assumptions in his analysis, both concerning the part of his paper dealing with light. First, he supposed that the radiation from stars is mostly confined to the visible region of the spectrum, and secondly he supposed that stars frequently move through space at a significant fraction of the speed of light. Having made these incorrect premises, it was a fairly simple step for Doppler to predict that the apparent colour and brightness of any star would depend on its state of motion in the line of sight. Namely, an approaching object will appear brighter and bluer, a receding one fainter and redder than the same object at rest. Doppler assumed most stars to be altruistically white or slightly yellow and considered the existence of coloured stars to be direct evidence in support of his theory.

Ernst Mach (1838–1916), 150th birth anniversary: Austria 1988, *Scott* 1419.

Attempts to apply Doppler's theory to light waves were also made by the Austrian physicist and philosopher Ernst Mach (1838–1916). Mach, however, is mostly remembered for his contributions to the study of shock waves. The ratio of the speed of an object moving through air, or any fluid substance, divided by the speed of sound as it is in that substance, is now called the Mach number. The Aérospatiale-BAC Concorde aircraft was a turbojet-powered supersonic passenger airliner, flying regular transatlantic flights connecting London and Paris with New York and Washington. The Concorde had an average cruise speed of Mach 2.02 (about 2,140 km/h), more than twice the speed of a conventional aircraft.

Mach 2.23, Concorde sets new speed record on 26 March 1974: Sierra Leone 2007.

A strong opponent of Doppler's theory was the Hungarian mathematician, inventor, and physicist of German origin Josef Maximilian Petzval (1807–1891), who was then professor of mathematics at the University of Vienna. He is considered to be one of the main founders of geometrical optics, modern photography, and cinematography. Petzval is also credited with the discovery of the Laplace transform and is known for his extensive work on aberration in optical systems.

(on the left) Josef Maximilian Petzval (1807–1891), with Čeněk Strouhal (1850–1922) & Vojtěch Jarník (1897–1970), 125th anniversary of the Union of Czechoslovakian Mathematicians and Physicists: Czechoslovakia 1987, *Scott* 2664.

Other critics of Doppler included the Dutch physicist Hendrik Antoon Lorentz (1853–1928), who shared the 1902 Nobel Prize in physics with Pieter Zeeman (1865–1943) for the discovery and theoretical explanation of the Zeeman effect.

Josef Petzval's photographic lens, EUROPHOT Photographic Congress, Vienna: Austria 1973, *Scott* 956.

Albert Einstein (1879–1955) with Hendrik Antoon Lorentz (1853–1928): Tuvalu 2005, *Scott* 981a.

Pieter Zeeman (1865–1943), joint Nobel prizewinner in physics (with Hendrik Antoon Lorentz): Guinea-Bissau 2009.

Among the many scientific achievements of Lorentz is the derivation of the transformation equations subsequently used by Albert Einstein (1879–1955) to describe space and time. In 1907, Lorentz published Doppler's papers [2], noting that "... considering the importance of [Doppler's] principle and the productive use to which it has been put, we must include Doppler as one of the great men of science, although it seems to me, that neither his other work nor the manner in which he defended his theory against various objections and applied it to the colours of the stars, confer on him any claim to such a honorific title."

Doppler also had supporters. One of them was Bernhard Placidus Johann Nepomuk Bolzano (1781–1848), a Bohemian mathematician, theologian, philosopher, logician, and antimilitarist.

Bolzano, whose mother tongue was German, strongly supported Doppler's academic career, particularly during Doppler's stay in Prague where he presented his seminal paper on 25 May 1842.

Bernhard Placidus Johann Nepomuk Bolzano (1781–1848): Czechoslovakia 1981, *Scott* 2352.

University of Vienna, 625th anniversary & Vienna Technical University, 175th anniversary, university seals: Austria 1990, *Scott* 1491.

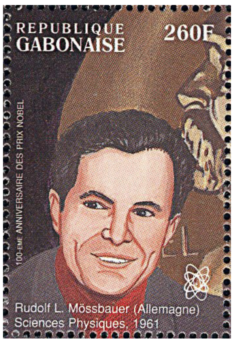
In March 1848 Doppler moved to Vienna, where he was appointed as the founding Director of the Institute for Experimental Physics at the University of Vienna in 1850. While there, Doppler, along with Franz Joseph Andreas Nicolaus Unger (1800–1870), an Austrian botanist, paleontologist, and plant physiologist, played an influential role in the development of young Gregor Johann Mendel (1822–1884), an Augustinian priest and scientist, who is often called the "father" of genetics for his study of the inheritance of certain traits in pea plants.

Gregor Johann Mendel (1822–1884): Danzig 1939, *Scott* 238.

Mendel showed that the inheritance of these traits follows particular laws, which were later named after him. The significance of Mendel's work was not recognized until the turn of the 20th century; its rediscovery formed the foundation of the modern science of genetics.

The confirmation of the optical Doppler effect in the laboratory came well after it was effectively accepted in astronomy. The German physicist Johannes Stark (1874–1957) won the 1919 Nobel Prize in physics for his "discovery of the Doppler effect in canal rays and the splitting of spectral lines in electric fields". The British physicist Sir Joseph John "J. J." Thomson (1856–1940) invented the mass spectrometer and was awarded the 1906 Nobel Prize in physics for his "discovery of the electron and his work on the conduction of electricity in gases".

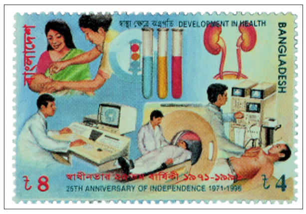
Sir Joseph John Thomson (1856–1940) & Johannes Stark (1874–1957), Nobel prizewinners in physics: Malagasy Republic (Madagascar) 1993, *Scott* 1132c.



Rudolf Ludwig Mössbauer (b. 1929), Nobel prizewinner: Gabon 1995, *Scott* 805b.

Another Nobel Prize in physics which involves the Doppler effect was awarded in 1961 to the German physicist Rudolf Ludwig Mössbauer (b. 1929) for the discovery of what is now known as the Mössbauer effect, a physical phenomenon which refers to the resonant and recoil-free emission and absorption of gamma ray photons by atoms bound in a solid form; the prize was shared with Robert Hofstadter (1915–1990). Mössbauer spectroscopy has been particularly useful in the field of geology for identifying the composition of iron-containing minerals.

There are many important applications of the Doppler effect in everyday life, including echocardiography, one of the most widely used diagnostic tests for heart disease. It can provide a wealth of helpful information, including the size and shape of the heart, its pumping capacity, and the location and extent of any damage to its tissues and valves. It can also detect abnormalities in the pattern of blood flow, such as the backward flow of blood through partly closed heart valves, known as regurgitation. By assessing the motion of the heart wall, echocardiography can help to detect the presence and assess the severity of coronary artery disease. The biggest advantage to echocardiography is that it is noninvasive and has no known risks or side effects.



Echocardiography equipment (lower left), development of health, 25th anniversary of independence: Bangladesh 1996, *Scott* 519.

The Doppler effect is used in various types of radar, to measure the velocity of detected objects. Instruments such as the laser Doppler velocimeter (LDV) and the acoustic Doppler velocimeter (ADV) have been developed to measure velocities in a fluid flow. The LDV emits a light beam and the ADV emits an ultrasonic acoustic burst, and measures the Doppler shift in wavelengths of reflections from particles moving with the flow. In military applications the Doppler effect is used to ascertain the speed of a submarine using both passive and active sonar systems.

Another use of the Doppler effect, found mostly in plasma physics and astronomy, is the estimation of the temperature of a gas (or ion temperature in a plasma) which emits a spectral line. Due to the thermal motion of the emitters, the light emitted by each particle can be slightly red- or blueshifted, and the net effect is a broadening of the line. This line shape is called a Doppler profile.

Images from the Hubble Space Telescope: Eagle Nebula, Ring Nebula, Lagoon Nebula, Egg Nebula, Galaxy NGC1316.
World Stamp Expo, Anaheim, California, July 2000: USA 2000, *Scott* 3388v.

In physics and astronomy, redshift occurs when electromagnetic radiation emitted or reflected by an object is shifted towards the (less energetic) red end of the electromagnetic spectrum due to the Doppler effect or other gravitationally-induced effects. More generally, redshift is defined as an increase in the wavelength of electromagnetic radiation received by a detector compared with the wavelength emitted by the source. This increase in wavelength corresponds to a drop in the frequency of the electromagnetic radiation. Conversely, a decrease in wavelength is called blue shift. [100]

The souvenir sheet of stamps shows images from the Hubble Space Telescope (HST), a telescope that was carried into orbit in April 1990. Although not the first space telescope, the HST, named after the American astronomer Edwin Powell Hubble (1889–1953), is one of the largest and most versatile, and is well known as both a vital research tool and a public relations boon for astronomy. Hubble profoundly changed our understanding of the universe by demonstrating the existence of other galaxies besides the Milky Way. Hubble is generally credited with discovering the redshift of galaxies, which can be interpreted as a measure of recession speed, and indicating that the degree of redshift observed in light coming from a galaxy increases in proportion to the distance of that galaxy from the Milky Way. This became known as Hubble's law, and would help to establish that the universe is expanding and that the greater the distance between any two galaxies, the greater their relative speed of separation.

Earlier, Albert Einstein had found that his newly developed theory of general relativity indicated that the universe must be either expanding or contracting. Unable to believe what his own equations were telling him, Einstein introduced a cosmological constant (a "fudge factor") to the equations to avoid this "problem". When Einstein heard of Hubble's discovery, he said that changing his equations was "the biggest blunder of [his] life".

The souvenir sheet features five stamps with images from the Hubble Space Telescope of the Eagle Nebula, Ring Nebula, Lagoon Nebula, Egg Nebula, and Galaxy NGC1316. The "Ring Nebula" (shown on the second stamp in the top row) is located in the northern constellation of Lyra, and also catalogued as Messier 57, M57 or NGC 6720. Planetary nebulae are formed after medium or low mass stars, such as the Sun, exhaust their hydrogen fuel in the stellar core. At this point the structure of the star changes so it can achieve a new equilibrium condition in which it can continue to burn; the outer layers of the star expand

and it becomes a red giant . In the outer region of the ring, part of the reddish hue is caused by hydrogen emission forming part of the Balmer series of lines [100].

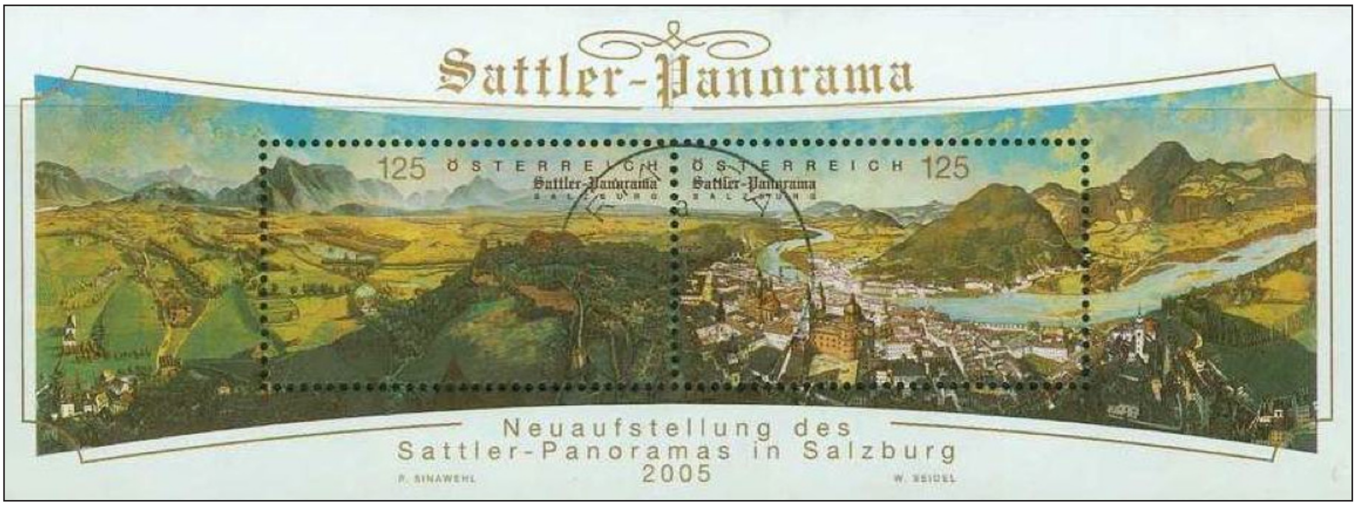
The souvenir sheet of 20 stamps arranged in a 4×5 rectangle may be augmented with a fifth row with each of the five stamps (as shown above) to yield a 5×5 "philatelic Latin square" [13, 49, 90] in which each stamp appears precisely once in each row and in each column. This Latin square, L say, has several interesting properties [13]. In particular it is of the type known as a "knight's move" or "Knut Vik" design, as described by Preece [65]:

"Of Latin squares used for crop experiments with a single set of treatments, the earliest examples (published in 1924) are 5×5 squares of the systematic type known as Knut Vik [93] or "knight's move" designs (Knut Vik being a [Norwegian] person, not a Scandinavian translation of "knight's move"!); these are squares where all cells containing any one of the treatments can be visited by a succession of knight's moves (as in chess) and where no two diagonally adjacent cells have the same treatment."

In 1931 Tedin [91] observed that there are just two possible arrangements of the 5×5 Knut Vik design in standard-form: A, B, C, D, E in sequence in the top row. Our Latin square L has the arrangement [91, Fig. 1, Arr. 1]

$$\begin{pmatrix} A & B & C & D & E \\ C & D & E & A & B \\ E & A & B & C & D \\ B & C & D & E & A \\ D & E & A & B & C \end{pmatrix},$$

which is a two-steps backwards circulant. Yates [103], following Tedin [91], notes that L is a special balanced 5×5 Latin square in which the treatments are as evenly spaced as possible. Moreover, L is pandiagonal, in that all diagonals (the two main diagonals and all broken diagonals) contain each of the five treatments precisely once [13].



Cyclorama of Salzburg by Johann Michael Sattler (1786–1847)[4]: Austria 2005, *Scott* 2028.

Christian Andreas[5] Doppler was baptized on 29 November 1803 in the St. Andrä church in Salzburg [76, p. 17] just four hours after his birth in the family house in what is now the Makartplatz (then Hannibalplatz), which is a few minutes walk from the church and close to the then residence house of Wolfgang Amadeus Mozart (1756–1791). The Makartplatz is named after Hans Makart (1840–1884), an Austrian academic history painter, well known for his influence on the Austrian symbolist painter Gustav Klimt (1862–1918).

Hans Makart (1840–1884), self-portrait, 150th birth anniversary: Austria 1990: *Scott* 1504.

In 1835 Doppler was appointed Professor of Elementary Mathematics and Accounting at the State Secondary School in Prague. On 6 March 1841 Doppler became full Professor of Mathematics and Practical Geometry at the Technical Institute in Prague, and it was in this position that on 25 May 1842 he presented the paper that ultimately made his name famous. The Royal Bohemian Academy of Sciences elected Doppler to full membership in 1843 and in 1847 he received an honorary doctorate from the University of Prague.

[4] Johann Michael Sattler (1786–1847) was an Austrian portrait and landscape painter, best known for his large-scale panoramas. In 1819 Sattler moved to Salzburg, where in 1824 he began to paint a 360-degree panorama of the city as seen from the top of Salzburg's castle. The massive work covered 125 square metres and was first exhibited in 1829. The painting is now on display at the Salzburg Museum in a specially designed area called the Panorama Museum. [100]

[5] When a second given-name is used, Doppler is often referred to as "Christian Johann" or sometimes "Johann Christian" (or just the initials C. J. or J. C.) [21, 32, 37, 58, 69, 79, 99]. The correct given-names, Christian Andreas, established by Alec Eden from the original records of baptism [76, p. 17], seems not to have appeared in print until 1985 [21].

Prague, Czechoslovak Academy of Sciences[6] , 25th anniversary: Czechoslovakia 1977, *Scott* 2146.

On 23 October 1847, Doppler became Professor of Mathematical Physics and Mechanics at the Mining Academy in Schemnitz (now Banská Štiavnica in Slovakia).

Banská Štiavnica (Schemnitz), UNESCO World Heritage Site: Slovakia 1995, *Scott* 228.

The unrest that accompanied the Hungarian revolution forced Doppler to return to Vienna after less than two years [64]. The Hungarian Revolution of 1848 was one of many revolutions that year and was closely linked to other revolutions of 1848 in the Habsburg areas. The revolution in Hungary grew into a war for independence from Habsburg rule. The anniversary of the revolution's outbreak, on 15 March 1848, is one of Hungary's three national holidays.

In 1848 Doppler was elected a full member of the Austrian Academy of Sciences in Vienna [22]. By a decree of the Emperor Franz Josef I (1830–1916) of 17 January 1850, he was appointed to the Chair of Experimental Physics at the University of Vienna and to be the founding Director of the Institute of Physics.

Vienna, Austrian Academy of Sciences, 150th anniversary, with Socrates (c. 469–399 BC): Austria 1997, *Scott* 1716.

Emperor Franz Josef I (1830–1916): Austria 1914, *Scott* B1 & B2.

Fate did not allow Doppler two years for the foundation of his new institute. Already in November 1852 he was compelled to take a holiday in Venice (which at the time was part of Austria) in the hopes of obtaining relief from his deteriorating pulmonary problems. The mild climate of Venice did not provide the expected palliation. After five months illness, he died at 5 a.m. on 17 March 1853 in the Venetian Parish of San Giovanni in Bragora—the parish where the baroque composer and Venetian priest Antonio Lucio Vivaldi (1678–1741) was born and baptized [22].

Venice, Saint Mark's Square and the Moon: Italy 2009.

Acknowledgements. Special thanks go to Klaus Schmidt for inviting us to write this article and to Nicolas Ammerlaan for his help in translating the articles by Buys Ballot [8, 9], Calmthout [11] and Exalto & Guerts [29]. Many of the images of stamps come from the excellent open-access websites [16, 52, 55, 62, 67]. Much of our biographical information is based on that in MacTutor [57] and *Wikipedia* [100]. Many thanks to Marika Asimakopulos, Maria Delmàs Ruiz, Marc Masdeu Sabaté, Aliza K. Miller, Daniel J. H. Rosenthal, Janice Simpkins, Evelyn Matheson Styan, and Götz Trenkler for their help. Research was supported, in part, by the Alexander von Humboldt Foundation and the Natural Sciences and Engineering Research Council of Canada.

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Impressions of a Junior Research Fellow

Maria Anastasia Jivulescu

Only a few weeks ago I ended my stay as Junior Research Fellow of The Erwin Schrödinger Institute and it is now my great pleasure to describe this challenging experience.

It all started in 2008 once with my decision to apply for an ESI scholarship to attend the program on "Entanglement and correlations in many-body quantum mechanics" organized by the institute in August/October 2009. As a researcher in the field of Mathematical Physics, I have always been aware of the potential of Vienna's academic environment, strongly strengthened by the existence of this institute specialized in promoting programs that are lying at the border of mathematics and physics.

My fascination for Vienna has deeper roots. Over the centuries almost all the famous Romanian scientists, writers or artists have included Vienna as an essential step in their career. Furthermore, I have always developed a personal curiosity to understand why Timisoara, the city that hosts my home university "University Politehnica Timisoara", is historically called "The Little Vienna". Now I know why!

I discovered Vienna on one of the most torrid days in summer of 2009. The Institute immediately welcomed me with the kind smiles of the administrative staff, offering me at the same time a refreshing and quiet place which sent myself to study. In few days it all started with the workshop "Quantum Computation and Quantum Spin Systems", as part of the program that I was planning to attend. Soon I understood that the time and the space didn't matter anymore, that science has no borders. My presence at the Institute was the ticket to a world where I could meet people from everywhere, working in the same field of research. Suddenly I was able to be connected to the last developments in the field of quantum spin systems and to learn new techniques for the understanding of their behaviour. I had also the chance to introduce myself to the other participants through the topic of research that I was doing. The atmosphere of those days at Vienna strengthened my belief that we all share the passion for research, beside the natural competition that appears between us.

My activity at the ESI proceeded till late in autumn giving me the chance to attend other programs, to listen to interesting talks and to take part in long discussions with other ESI guests. I will always remember with pleasure the Monday morning emotions looking for the new pictures that had been added to the "Visitors Photo Board" of the Institute.What a nice surprise to discover a new famous professor as my officemate of the week! Scientists from Japan, China, U.S.A, Italy, Poland, Denmark, Israel, Germany, U.K., to mention only few of them, gathered in the warm embrace of Vienna. It is the Institute's policy to put the scientific world in contact. You never get tired of discussing with others about your research, of listening to them and of sharing impressions. It is the best way of getting to know yourself, reaching your goals and finding new challenges.

These are parts of my memories about the activity at the Institute. Its location in a city like Vienna is an added value, mainly due to the variety of the people that live in or close to it. I was lucky to set friendship with some people that work at the Faculty of Physics and Mathematics of the University of Vienna, as well as scientific contacts with the research groups from RCQI-Bratislava and Institute of Applied Mathematics, Klagenfurt.

What about "Great Vienna"? I discovered it happy and shining during my long bike rides during the beautiful days of autumn 2009. I have also admired its sobriety as an old royal capital living together with the modern features of an European city. I will never forget the total sensation of freedom that was dominating the people's feelings inside the court of the Museum Quartier.

Maybe my words are too few to describe this extraordinary experience I have had. It all made me feel a sense of personal achievement, but at the same time opened new gates.

I am grateful to the ESI scientific and administrative staff who made my stay at Viena unforgettable and I invite all the young researchers to live an experience as mine.

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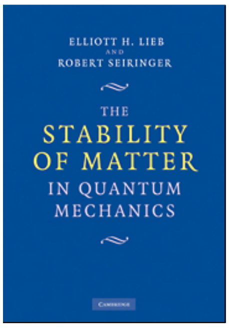
ESI News

Elliott H. Lieb and Robert Seiringer: The Stability of Matter in Quantum Mechanics. Cambridge: Cambridge University Press 2009



Elliott H Lieb, Princeton University, New Jersey, and Robert Seiringer, Princeton University, New Jersey and University of Vienna have written a book on the stability of matter.

Research into the stability of matter has been one of the most successful chapters in mathematical physics, and is a prime example of how modern mathematics can be applied to problems in physics. A unique account of the subject, this book provides a complete, self-contained description of research on the stability of matter problem. It introduces the necessary quantum mechanics to mathematicians, and aspects of functional analysis to physicists. The topics covered include electrodynamics of classical and quantized fields, Lieb-Thirring and other inequalities in spectral theory, inequalities in electrostatics, stability of large Coulomb systems, gravitational stability of stars, basics of equilibrium statistical mechanics, and the existence of the thermodynamic limit. The book is an up-to-date account for researchers, and its pedagogical style makes it suitable for advanced undergraduate and graduate courses in mathematical physics.

Content

Walter Thirring, Honorary President and founding father of the ESI, did not pass the final exam of the Austrian schooling system, the *Matura*, due to circumstances during war times while he was serving – among others – as a *Flakhelfer*. Nevertheless, after the end of WW II without having the proper entrance ticket for university studies he was accepted by Arthur Mach, professor of theoretical physics at the University of Innsbruck, to attend university courses.

With a ceremony on December 3, 2009, the Gymnasium *Neulandschule Grinzing*, which Thirring attended during wartimes, will award him a *Honorary Matura*.

We congratulate Walter Thirring for finally having settled a crucial requirement to start an academic carrier.

Robert Seiringer was awarded the **Poincaré Price 2009**.

Seiringer was honored for his major contributions to the mathematical analysis of low temperature condensed matter systems, in particular for his work on Bose condensation and the Gross-Pitaevskii equation.

Laudatio for Robert Seiringer

by Jakob Yngvason

It is my privilege to present to you Robert Seiringer who receives the Henri Poincaré Prize for his *'major contributions to the mathematical analysis of low temperature condensed matter systems'*.

Triggered by experimental advances, cold quantum gases and Bose-Einstein condensation came into the focus of attention of physicists about fifteen years ago and this topic is currently one of the most active research areas in physics. Mathematical physics has here an important role to play because due to the complexity of the quantum many-body problem some of the most fundamental questions can only be settled by penetrating mathematical analysis. It is here that Robert has been a key player and contributed deep insights.

It is now ten years since Robert came to me inquiring about a subject for a Master thesis. It so happened that Elliott Lieb and I had a little earlier written a paper on the ground state energy of an interacting, dilute Bose gas and were thinking about the extension to inhomogeneous systems. Physicists usually describe such systems by the Gross-Pitaevskii equation that is a non-linear Schrödinger equation expected to provide a good approximation to the many-body problem in the case of dilute gases. But no rigorous derivation starting from the full many-body problem existed yet. As a first task I suggested to Robert to work on the energetic upper bound.

This was on a Friday. A normal, good student would probably have started by studying lots of references and come back after three weeks, asking for further guidance. But I realized that Robert was someone quite out of the ordinary when he presented to me next Monday a beautiful LaTeX document with the complete solution of the problem. Thus Robert was from the very outset a full-fledged research partner rather than a student or junior partner and this first cooperation between Elliott, Robert and me very soon resulted in a joint publication as well as RobertÕs Master degree.

His PhD followed a year later, his thesis containing besides further contributions to the theory of Bose gases some beautiful results about quite a different topic, namely atoms in strong magnetic field, partly obtained in collaboration with Bernhard Baumgartner. At the age of 33 Robert is at present author or co-other of more than 40 original publications in prestigious journals. These publications are devoted to many different topics but I shall here focus on a few that are particularly linked to the citation for the Henri Poincaré prize.

A notoriously difficult problem in quantum many-body theory is to prove the existence of Bose-Einstein condensation (BEC) for a system of interacting Bosons in the thermodynamic limit. This phase transition is accompanied by spontaneous breaking of a continuous symmetry (gauge symmetry), which explains at least partly the difficulty in proving it. In fact, for a continuous system with realistic interactions this is still an open problem. Experiments with cold atoms are, however, carried out in traps where the gas has a finite extension and a simpler, but still far from an easy problem is to prove Bose-Einstein condensation in an appropriate limit, called the Gross-Pitaevskii (GP) limit, for such systems. In fact, this had been an open problem for quite some time when Robert entered the scene.

Robert, who in the meantime had moved from Vienna to Princeton with a scholarship of the Austrian Science Fund, realized that the energy estimates used in the derivation of the Gross-Pitaevskii equation could be generalized to prove that the kinetic energy of the ground state wave function is essentially localized in small regions in configuration space and that this would be the key to a proof of BEC in the GP limit. An additional ingredient, namely a generalization of classical Poincaré inequalities, was also needed, and all this was put together in a beautiful joint publication of Robert and Elliott Lieb in 2002. This was the first derivation of BEC for an interacting system of direct experimental relevance.

The theory of BEC in the Gross-Pitaevskii limit was subsequently generalized to prove also superfluidity in this limit and somewhat later a further outstanding problem, posed six years earlier by Lev Pitaevskii, could be solved, namely the derivation of the Gross-Pitaevskii equation and the proof of BEC for gases in a rotating container. This problem is much more complex than for the non-rotating case due to the occurrence of quantized vortices that can break rotational symmetry. Here the solution was obtained in several steps with two papers of Robert playing a key role. One is his analysis of the Gross-Pitaevskii equation for a rotating system, containing the first general proof of rotational symmetry breaking for this equation.

Most work on the Gross-Pitaevskii equation with rotation is concerned with asymptotic analysis with respect to a small parameter, the ratio of the healing length to the size of the system, but Robert's paper is one the few that has no such limitations. In a second paper Robert linked the symmetry breaking to another important difference between the rotating and non-rotating case: while in the non-rotating case the absolute ground state, i.e., the ground state without symmetry restrictions, is automatically the Bose ground state, this is in general no longer true for rotating systems. He was nevertheless able to prove that the Gross-Pitaevskii equation provides an upper bound to the bosonic ground state, also in the case of symmetry breaking. The derivation of the Gross-Pitaevskii equation in the rotating case was finally completed when the lower bound was proved in an impressive joint paper with Elliott Lieb.

Further work of Robert on rotating Bose gases includes quite recent papers with Mathieu Lewin, and with Elliott and myself on gases that are in such rapid rotation that they become effectively two-dimensional and their state confined to the lowest Landau level. Besides his work on the ground states, Robert has also been a pioneer in the rigorous study of quantum gases at nonzero temperatures. His work here includes the proof of the next to leading order term in the pressure of a dilute Fermi gas, generalizing previous joint work with Lieb and Solovej on the ground state, and a highly sophisticated derivation of a lower bound to the free energy of a Bose gas, containing next to leading order contributions. A beautiful recent paper with Daniel Ueltschi contains rigorous upper bounds for the transition temperatures for superfluidity in two-dimensions and to BEC in a three dimensions. As already mentioned, Robert has worked on many topics besides cold quantum gases, including Coulomb systems, quantum electrodynamics and BCS theory, partly in collaboration with another former student of mine, Christian Hainzl. All his work is characterized by depth of the mathematical analysis and elegance and clarity of the presentation. His accomplishments make him already at this early stage of his career a most deserving recipient of the Henri Poincaré Prize and point to a bright future.

I congratulate him heartily on this occasion.

New Activity in Physics and Philosophy of Science in Collaboration with the University of Vienna:

As a joint initiative of philosophers of science and physicist of the University of Vienna a interdisciplinary symposium on the topic

(Un)Conceived Alternatives. *Underdetermination of Scientific Theories between Philosophy and Physics*

will be held on 18 and 19 December, 2009 at the ESI.

The symposium aims to initiate a discussion between physicists and philosophers of science on the question of underdetermination.

Invited speakers:

Physics:

Markus Arndt (Vienna), "Underdeterminedness and the Quantum Superposition of Massive Objects"

Markus Aspelmeyer (Vienna), "Underdetermination in Quantum Physics"

Daniel Grumiller (Vienna), "Cosmology in the Multiverse"

Manfred Jeitler Vienna), "Particle Physics: From an Experiment-Driven to a Theory- Driven Field"

Karl Landsteiner (Madrid), "The Dual Use of String Theory"

Jakob Yngvason (Vienna), "Lessons from Quantum Field Theory"

Philosophy of Science:

Richard Dawid (Vienna), "Limitations to Underdetermination of Theory Building and their Role in Fundamental Physics"

Brigitte Falkenburg (Dortmund), "Underdetermination and the Phenomena of Physics"

Paul Hoyningen-Huene (Hannover), "The Miracle Argument and Transient Underdetermination"

Elisabeth Nemeth (Vienna), "Is there Any Use Physicists can Make of Philosophy of Science? Re-considering Philipp Frank on Science Teaching"

Miklos Redei (Budapest and London), "Diachronic Underdetermination in the Development of Relativistic Quantum Field Theory"

Kyle Stanford (Irvine), "Bush's Nightmare: Where (and When) do Unconceived Alternatives Pose a Serious Challenge to Scientific Knowledge?" .

The symposium is jointly organized by:

The Erwin Schrödinger International Institute for Mathematical Physics
The Faculty of Physics, Quantum Optics Group, University of Vienna
The Institute of Philosophy, University of Vienna
The Institute Vienna Circle

The symposium is sponsored by:

ID, Interdiszipliäres Dialogforum der Universität Wien
The Faculty of Physics, Quantum Optics Group, University of Vienna
The Institute of Philosophy, University of Vienna
The Institute Vienna Circle

The closing conference of the *Initiativkolleg* **Sciences in Historical Contexy**, a Ph.D.- Programme of the University of Vienna, will be held at the *Schrödinger Lecture Hall* on 27 and 28 November, 2009.

New ESI Lectures in Mathematics and Physics

Hans Ringström

The Cauchy Problem in General Relativity

Zürich: European Mathematical Society Publishing House 2009.

The book presents complete proofs of several classical results that play a central role in mathematical relativity but are not easily accessible to those wishing to enter the subject. Prerequisites are a good knowledge of basic measure and integration theory as well as the fundamentals of Lorentz geometry. The necessary background from the theory of partial differential equations and Lorentz geometry is included.

News from the Scientific Community

The **Henri Poincaré Prize**, sponsored by the Daniel Iagolnitzer Foundation, was created in 1997 to recognize outstanding contributions in mathematical physics, and contributions which lay the groundwork for novel developments in this broad field. The Prize is also created to recognize and support young people of exceptional promise who have already made outstanding contributions to the field of mathematical physics. The prize is awarded every three years at the International Mathematical Physics Congress and in each case, is an award to three individuals (to be exact, the rules say approximately three allowing for exceptional circumstances, at the discretion of the prize committee).

The **Henri Poincaré Prize 2009** was awarded to **Jürg Fröhlich**, **Robert Seiringer**, **Yakov G. Sinai**, and **Cedric Villani**.

All friends of the ESI are cordially invited to a Christmas Party at the Institute on Tuesday, December 15, 2009, 5.00 p.m.

Current and Future Activities of the ESI

Thematic Programmes 2009

Entanglement and correlations in many-body quantum mechanics, August 18 – October 17, 2009

Organizers: B. Nachtergaele, F. Verstraete and R. Werner

The dbar-Neumann problem: analysis, geometry and potential theory, October 27 - December 24, 2009

Organizers: F. Haslinger, B. Lamel, E. Straube

Thematic Programmes 2010

Quantitative Studies of Nonlinear Wave Phenomena, January 7 - February 28, 2010

Organizers: P.C. Aichelburg, P. Bizon, W. Schlag

Quantum field theory on curved space-times and curved target-spaces, March 1 - April 30, 2010

Organizers: M. Gaberdiel, S. Hollands, V. Schomerus, J. Yngvason

Matter and radiation, May 3 - July 30, 2010

Organizers: V. Bach, J. Fröhlich, J. Yngvason

Topological String Theory, Modularity and Non-Perturbative Physics, June 7 - August 15, 2010

Organizers: L. Katzarkov, A. Klemm, M. Kreuzer, D. Zagier

Anti - de Sitter holography and the quark-gluon plasma: analytical and numerical aspects, August 2 - October 29, 2010

Organizers: A. Rebhan, K. Landsteiner, S. Husa

Higher Structures in Mathematics and Physics, August 15 - November 15, 2010

Organizers: A. Alekseev, H. Bursztyn, T. Strobl

Thematic Programmes 2011

Bialgebras in free Probability, February 1 - April 22, 2011

Organizers: M. Aguiar, F. Lehner, R. Speicher, D. Voiculescu

Nonlinear Waves, April 4 - June 30, 2011

Organizers: A. Constantin, J. Escher, D. Lannes, W. Strauss

Dynamics of General Relativity: Numerical and Analytical Approaches, July 4 - September 2, 2011

Organizers: L. Andersson, R. Beig, M. Heinzle, S. Husa

Combinatorics, Number theory, and Dynamical Systems, October 17 - December 17, 2011

Organizers: M. Einsiedler, P. Grabner, C. Krattenthaler, T. Ziegler)

Other Scientific Activities in 2009

Entanglement and Correlations in Many-Body Quantum Mechanics, August 10 – October 17, 2009

Organizers: B. Nachtergaele, F. Verstraete, R. Werner

Classical and Quantum Aspects of Cosmology, September 28 – October 2, 2009

Organizers: P. C. Aichelburg, H. Rumpf

Recent Advances in Integrable Systems of Hydrodynamic Type, October 12 – October 23, 2009

Organizers: A. Constantin, J. Escher

6th Vienna Central European Seminar on Particle Physics and Quantum Field Theory, November 27 – November 29, 2009.

The topic of the Seminar is **"Effective Field Theories"**.

This Semininar, organized by the Faculty of Physics, University of Vienna, is supported by the ESI.

Organizer: H. Hüffel

Symposium "Quanta and Geometry" , October 8 and 9, 2009

On the occasion of **Harald Grosse's** retirement from his position at the University of Vienna a Symposium will take place at the ESI on October 8 and 9, 2009 under the heading *Quanta and Geometry*.

The Symposium starts in the afternoon of Thursday, October 8 with an Erwin Schrödinger Lecture by **Vincent Rivasseau**, followed by a reception at the ESI.

On October 9 there will be further lectures by **Fritz Gesztesy**, **Dorothea Bahns**, **Krzysztof Gawedzki** and **Volker Schomerus**.

Organizer: Alan Carey, Joachim Schwermer, Jakob Yngvason

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dbar-Neumann Problem: Analysis, Geometry and Potential Thery, October 27 – December 23, 2009

Organizers: R. Bürger, A. G. Jones, S. J. Arnold

Erwin Schrödinger Lectures

Fall Term 20009

The Erwin Schrödinger Lectures are directed towards a general audience of mathematicians and physicists. In particular it is an intention of these lectures to inform non-specialists and graduate students about recent developments and results in some area of mathematics or mathematical physics.

These lectures take place in the Boltzmann Lecture Room of the ESI.

Each lecture will be followed by an informal reception at the Common Room of the ESI.

Vincent Rivasseau (Laboratoire de physique théorique, University Paris-Sud XI, Orsay, France): *Renormalization, an enduring love story between quanta and geometry.* October 8, 2009

Senior Research Fellows Lecture Courses

Fall Term 2009

To stimulate the interaction with the local scientific community, the ESI offers lecture courses on an advanced graduate level. These courses are taught by Senior Fellows of the ESI, whose stays in Vienna are financed by the University of Vienna, the Vienna University of Technology, and the Austrian Federal Ministery for Education, Science and Culture.
These courses take place in the Erwin-Schrödinger Lecture Room of the ESI.

Jeff McNeal (Ohio State University, Columbus)

L^2 - Methods in Complex Analysis, October 26 - November 2009, December 6 - December 19, 2009

In this course I'll discuss how to use Hilbert space techniques to solve the Cauchy-Riemann equations on domains in C^n and on complex manifolds. These techniques are quite flexible and we will explore the variety of L^2 estimates on the Cauchy-Riemann operator that are known to exist, including the relatively recent "twisted" estimates. I'll also give many applications of these estimates throughout the course. Some of the directions we'll apply the estimates to are: the boundary behavior of the Bergman kernel, extension theorems of Ohsawa-Takegoshi type, compactness of the d-bar Neumann operator, and the boundary behavior of biholomorphic mappings between domains in C^n.

Peter West (King's College, London)

Supergravity Theories, September 29 - October 30, 2009

In these lectures I will give an introduction to supergravity theories. I will begin with the four dimensional $N = 1$ supergravity explaining its construction and properties and then present the supergravity theories in ten and eleven dimensions. I will then discuss the E_n symmetries that arise in the maximal supergravity theories. The relevance of these results for string theory will be explained.

Lectures at the ESI on Physical and Mathematical Sciences in Historical Contexts

Nevena Ilieva-Litova (Bulgarian Academy of Sciences)
Pauli and the non-Abelian gauge theories: between physical intuition and mathematical logic
December 4, 2009

Since the late 60s, non-Abelian gauge theories (the Yang-Mills theories) are a dominant approach in field theory. They have provided the basis of the most significant achievements in this field of modern physics. The history of their development and the milestones on that way are rather well known. Less known is the ingenious insight into their geometric beauty that Wolfgang Pauli had gained and the dramatic conflict between physical intuition and mathematical logic which cast shadow over the last year of his life.

Previous lectures on physical and mathematical sciences in historical context at the ESI:

2005:

Leo Corry (The Cohn Institute for History and Philosophy of Science and Ideas, Tel-Aviv University):
Hilbert's Axiomatic Approach to the General Theory of Relativity: From "Grundlagen der Geometrie" to "Grundlagen der Physik"

Jeremy Gray (Centre for the History of the Mathematical Sciences, Faculty of Mathematics, Open University, Milton Keynes, U.K.):
Poincaré and Fundamental Physics

2006:

Catherine Goldstein (CNRS, Paris, Institut mathèmatique de Jussieu):
Geometry and Nature according to A. N. Whitehead

2007:

Dieter Hoffmann (Max Planck Institut für Wissenschaftsgeschichte, Berlin):
Zwischen Autonomie und Anpassung. Die Deutsche Physikalische Gesellschaft im Dritten Reich.

Moritz Epple (Universität Frankfurt):
Beyond Metaphysics and Intuition: Felix Hausdorff's View on Geometry

2008:

Scott Walter (Archives Henri Poincare, Nancy):
Hermann Minkowski and the Scandal of Spacetime

Jacques Bouveresse (Collège de France, Paris):
Ludwig Boltzmann und das Problem der Erklärung in der Wissenschaft

2009:

Scott Walter (Archives Henri Poincare, Nancy)
Hermann Minkowski and theoretical physics in Göttingen

Samuel J. Patterson (Göttingen)
The number theorist Hermann Minkowski

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The ESI is supported by the Austrian Federal Ministry for Science and Research (BM.W_F). The ESI Senior Research Fellows Programme is additionally supported by the University of Vienna.

This newsletter is available on the web at: ftp://ftp.esi.ac.at/pub/ESI-News/ESI-News4.1.pdf

IMPRESSUM: **Herausgeber, Eigentümer und Verleger**: INTERNATIONALES ERWIN SCHRÖDINGER INSTITUT FÜR MATHEMATISCHE PHYSIK, Boltzmanngasse 9/2, A-1090 Wien.
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Zweck der Publikation: Information der Mitglieder des Vereins Erwin Schrödinger Institut und der Öffentlichkeit in wissenschaftlichen und organisatorischen Belangen. Förderung der Kenntnisse über die mathematischen Wissenschaften und deren kultureller und gesellschaftlicher Relevanz.