1994 EQEC/CLEO-Europe

First Event a Landmark Success

With over 2200 participants, the first joint European Quantum Electronics Conference/ Conference on Lasers and Electro-Optics (EQEC/CLEO-Europe) held at the RAI Conference Centre, Amsterdam (28 August - 2 September 1994) proved to be a major success.

EQEC/CLEO-Europe is a new initiative aimed at strengthening the interplay between public-sector R&D and industrial development in one of the fastest growth areas of modern technology. In the US, CLEO organized in conjunction with the Quantum Electronics and Laser Science conference has successfully bridged the traditional gap between private and public R&D, notably by featuring a large technical exhibit in addition to the technical conference itself.

The link between academia and industry has historically been weaker in Europe than in the US. This was the main reason the Quantum Electronics and Optics Division (QEOD) of EPS decided to enter into a collaboration with sister organizations in the US to strengthen the impact of the Divisional EQEC event (organized biannually in Europe since 1986). The success of the Amsterdam meeting shows that this motivation was fully justified.

Integrating Research and Technology

EQEC and CLEO-Europe each have their distinct character, with EQEC covering the fundamental aspects of quantum electronics and CLEO-Europe primarily addressing applied area of lasers and electro-optics. The two distinguished European scientists who spoke during the single EQEC/CLEO-Europe plenary session of the joint conference nicely illustrated the linking of basic research and advanced technology. Both reviewed major recent developments, with H. Walther (Max-Planck Institute, Garching) discussing micromasers and associated studies of phenomena in quantum optics while D. Payne (Southampton) spoke on the revolution in telecommunications catalyzed by the advent of high-quality optical amplifiers. These are seemingly well-separated topics. However, over the next decade they will merge as quantum optical effects are predicted to enter the field of optical communication owing to stringent requirements on protocols for secure transmission.

The interplay between fundamental research and state-of-the-art applications was further emphasized in two joint symposia. The one on *Quantum Engineering of Photonic Materials* featured Y. Yamamoto (Stanford and Tokyo), who spoke on microcavity lasers, and C. Weisbuch (Ecole Polytechnique, Paris) who discussed cavity quantum electrodynamics in multiple quantum-well structures. Both gave clear evidence that optical microcavities represent a fast maturing field (see page 205) with many potential applications, including noise control in optical communications systems. E. Yablonovitch (Los Angeles) reviewed photonic bandgaps and semiconductor electronics. Among several fascinating topics, he described an intelligent programmable radar reflector that resembled a fence made of chicken wire.

EQEC '94 was chaired by G. Nienhuis (Leiden) and J. Mlynek (Constance), the QEOD Chairman, who is shown here with E. Labuda (IEEE-LEOS) and H. Melchinov (ETH, Zurich) on the left and right, respectively. In introducing the joint EQEC/CLEO-Europe plenary session, Professor Mlynek referred to the back-back event as a landmark in the evolution of the quantum electonics and optics community. It reflects Europe's considerable achievements as well as the professional and learned societies' ability to help meet the community's needs. He also acknowledged the support which was contributed and made available so that registration fees for some 110 participants coming from east and central Europe and the former Soviet Union could be waived in order to facilitate attendance.

The second joint symposium dealt with the *Production and Application of High Brightness Ultrafast Pulses*. This field has witnessed a very strong development of both fundamental and applied natures, catalyzed by the advent of new, powerful, short-pulse lasers. S. Szatmari (Göttingen) discussed table-top, high-power femtosecond excimer lasers, while three speakers covered high-brightness X-ray sources, among them E. Turcu (Rutherford Appleton Laboratory) and C. Schank (Berkeley) who reviewed applications of laser-generated X-rays for lithography and microscopy. This application is potentially very important because it is capable of introducing table-top X-ray sources into the electronics industry. The symposium also dealt with more fundamental issues, notably high harmonic generation in various media. Impressive progress was reported on the generation of tuneable XUV radiation featuring parametric mixing. The broad interest in high power and short-pulse lasers was accentuated by two well-attended tutorials given by B. Krupke (Lawrence Livermore National Laboratory) and F. Krausz (Vienna) that set the stage for the symposia presentations which followed.

Aside from high power and short pulse lasers, CLEO-Europe included highlights in the fields of waveguide- (fibre-) based lasers, with A.C. Tropper (Southampton) and R. Wyatt (British Telecom) giving invited talks on the rapid developments, including up- and down-conversion. On the EQEC side, the interesting properties embedded in the transverse degrees of freedom of laser fields (*i.e.*, transverse optical pattern formation) was discussed by several speakers, among them G.-L. Oppo (Strathclyde) who showed video recordings of calculated spontaneously generated patterns.

EQEC Symposia Attracted Many

Two EQEC symposia, *Cold Atoms* and *Atom Optics and Interferometry*, attracted large crowds on the last day of the joint conference. The leading scientists in these extremely active research areas gave a series of talks of a very high quality. The field of cold atoms is developing rapidly with the custom design of optical lattices for cold atoms. G. Grynberg (Paris) and T.W. Hänsch

A full house at the RAI for the 1994 EQEC/CLEO-Europe plenary session. *The 1994 EQEC/CLEO-Europe was sponsored by EPS, the IEEE/Lasers and Electro-Optics Society (LEOS), and the Optical Society of America, with the Quantum Electronics and Optics Division (QEOD) of EPS responsible for EQEC '94. The joint event was organized by a LEOS/OSA/QEOD steering committee, and the programme consisted of 8 parallel sessions, 3 EQEC sessions and 5 CLEO-Europe sessions. There were 2200 participants, including some 1500 for the conferences themselves and 300 who visited the industrial exhibition. Conference participants could register either for EQEC (40% chose this) or for CLEO-Europe, but both groups received the technical digests for the two events. A total of 1500 papers (600 for EQEC) were submitted from nearly 50 different countries: some 40% were selected for oral presentation, 30% were given as posters and 30% were rejected. In addition, nearly 60 invited papers in the EQEC part and 90 invited papers in CLEO-Europe ensured a high scientific quality of this first major European event in quantum electronics and lasers. The success of the meeting was greatly enhanced by the early acceptance of many of the invited speakers who thus lent their prestige.*

Ove Poulsen is the Director of the Microelectronic Centre, TU Lyngby, Denmark. He co-chaired the EQEC '94 Programme Committee with Elizabeth Giacobino from Paris.

QEOD Board Elects New Chair

M. Ducloy (Paris) and O. Poulsen (Lyngby), on the right. Professor Mlynek reported during the General Meeting of the Division held at the end of the EQEC/CLEO-Europe joint plenary session that Ducloy would be taking over from him next April. He also summarised the Division's wide-ranging activities including: plans for a "who's who" (the last was published in 1984); the Division newsletter in *Optics Communications*; a possible EPS prize in quantum electronics; conferences, notably the very successful European Research Conference in quantum optics, and of course EQEC in its new format; and finally, efforts to enhance relations with industry, the European Community and with the European Optical Society. Many scientists and engineers working in optics attended the 1994 EQEC/CLEO-Europe, thereby illustrating the optical community's high level of interest.

(Garching) discussed in detailed design criteria for the optical potentials in both two- and three-dimensions, and gave examples of unexpected cooperative effects resembling phenomena found in the solid state. The basic physical phenomena behind laser cooling of free and lightly bound atoms were reviewed by M.J. Phillips (National Institute of Science and Technology, Washington), a well-known pioneer of laser cooling, in an exceptionally clear presentation.

The EQEC symposium on *Atom Optics and Interferometry* had the same rare qualities as the symposium on cold atoms by offering a well-balanced series of talks by active researchers representing state-of-the-art activities in a rapidly growing field. The world of Newtonian physics was successfully merged with quantum physics by J. Dalibard (Paris), who described the motion of laser-cooled caesium atoms in a gravitational cavity (*i.e.*, a cavity that apparently has no magnetic field present). The extreme precision inherent in using laser-cooled free atoms in combination with atom interferometry was convincingly discussed by J. Helmcke (Physikalisch-Technische Bundesanstalt), and the fundamental measurement limits were reviewed by T. Pfau (Constance). A highlight of the symposium was an introduction to the (new) topic of non-linear atom optics by P. Meystre (Tuscon). The main problem in defining non-linear effects lies in the intricate interaction between atoms in optical fields.

Over 200 companies represented. *Aside from the conferences themselves, the 1994 EQEC/CLEO-Europe featured a large, three-day commercial exhibit where more than 200 companies displayed their latest innovations at 122 stands. The inclusion of a strong technical exhibit was an important part of the first EQEC/CLEO-Europe. It served as a meeting place not only for science and technology, but also for industrial participants and the large number (over 400) of students who could be inspired by new products and establish new contacts aimed at an eventual career in industry.*

G.-L. Oppo (Strathclyde), on the left, demonstrating his video of transverse optical patterns in laser fields, with L.A. Lugiatio (Milan) who takes over from E. Giacobino (Paris) as the QEOD Secretary next April.

1994 EQEC/CLEO-Europe HIGHLIGHTS

MONOLITHIC MINIATURE RESONATORS

Manipulating the Electromagnetic Field

A major success of quantum optics in the last decade has been the experimental demonstration that the quantum fluctuations of light can be modified: the fluctuations in one quadrature (the amplitude of the cos[qt] or sin[qt] component of the electric field) can be decreased ("squeezed") below the vacuum level, while those in the orthogonal increase correspondingly in order to satisfy the Heisenberg uncertainty relation. Squeezed light can be produced by subjecting a light mode to a nonlinear interaction of the type that gives rise to second-harmonic and sub-harmonic generation (so-called optical parametric oscillation).

Unfortunately, squeezed light is fragile: its nemeses are the ubiquitous propagation losses. To generate strongly squeezed light one must provide an environment in which the nonlinear interaction can act while the losses play a secondary role.

At present, the experimental emphasis relies on developing reliable and efficient sources of strongly squeezed radiation for a number of applications. An "all solid-state" approach has been adopted at the University of Constance by combining diode laser-pumped solid-state lasers and monolithic non-linear resonators (see photograph). Round-trip losses as low as 0.2% have been routinely achieved.

In a first experiment, a continuous-wave, single-mode wave from a frequency-tuneable Nd:YAG laser was resonantly injected into a monolithic resonator. The high circulating power that builds up within the cavity is converted to the harmonic wave (532 nm wavelength) which immediately escapes from the resonator. When the device is operated in an input-power regime such that the external power conversion efficiency is high, the harmonic wave exhibits intensity noise below the vacuum level. A reduction of 30% has been measured, with more than 50 mW of optical power [Paschotta *et al.*, *Phys. Rev. Lett.* **73** (1994) 3807]. This source is remarkably stable over many hours, and represents a very simple and reliable way of producing squeezed light.

Besides bright squeezed light, the generation of squeezed vacuum is also of great

1996 EQEC/CLEO-Europe

The 1996 joint European Quantum Electronics Conference/Conference on Lasers and Electro-Optics — Europe will be held in France or Germany in September 1996. In view of rapid developments, there will be two new EQEC session (on atom optics and on cold atoms). The CLEO-Europe general chairs are D.C. Hanna and J.-P. Huignard; the EQEC general chairs are O. Poulsen and E. Giacobino.

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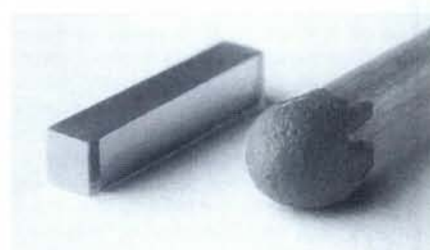
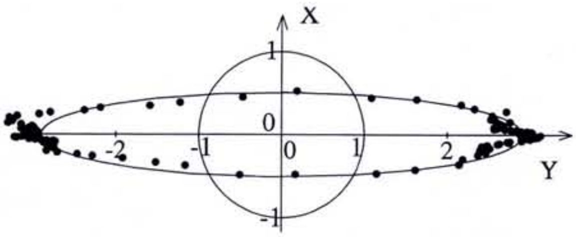


Monolithic nonlinear optical resonator. Shown is a resonator fabricated out of a lithium-niobate single crystal whose ends are accurately polished into a spherical shape. Multilayer dielectric coatings are sputtered directly onto the end faces of the crystal.



"Squeezing ellipse", showing the measured reduced and excess quantum noise in the electric field quadratures of a squeezed vacuum. The circle indicates the usual zero-point vacuum fluctuations. The ellipse area exceeds the circle area owing to the effect of the small, but finite, system losses.

interest for a number of applications. Squeezed vacuum is characterized by a vanishing expectation value of the electric field, but reduced fluctuations in one quadrature. A parametric amplifier is used to generate light of this type. The monolithic resonator employed in the "squeezing" experiment was operated "in reverse", namely pumped by a 532 nm wave. When the pump power was below the threshold of 28 mW, squeezed vacuum was generated, with a measured 55% reduction in quantum noise power in one quadrature (see figure).

While squeezed vacuum of this sort is obtained when "normal" vacuum at 1064 nm enters the cavity, it is also possible to inject a weak laser beam, giving rise to low-power squeezed light. In this arrangement, a 65% quantum noise reduction was observed.

The systems described are compact, efficient, and highly reliable. The all-solid-state, monolithic, approach is therefore well suited for applications of squeezed light in complex experiments, such as gravitational wave detection. The development of low-loss nonlinear resonators is also important for other quantum-optical experiments. Moreover, the requirements that benefit strong squeezing also lead to highly efficient frequency conversion. More than 80% power conversion was obtained with the monolithic resonator in harmonic generation as well as in subharmonic generation with a pump power four times above oscillation threshold.

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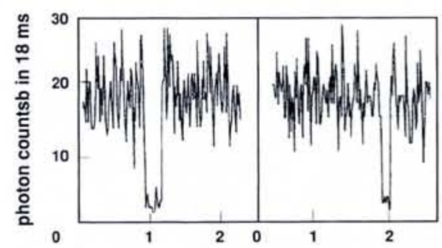
University of Constance

FREQUENCY STANDARDS

Spectroscopy of a Single Laser-Cooled Indium Ion

A single laser-cooled ion stored in a radiofrequency trap forms an ideal spectroscopic sample that is practically free of frequency shifts and line broadening mechanisms. Laser spectroscopy of forbidden transitions with natural linewidths in the 1 Hz range therefore offers the potential for very high resolution and might form the basis of a new generation of atomic frequency standards.

The single charged In^+ ion is an excellent candidate for these applications. We laser-cool it by exciting the intercombination line $5s^2\,{}^1S_0 \rightarrow 5s5p\,{}^3P_1$ at a wavelength of 230.6 nm. Presently we reach temperatures of less than 20 mK, but values down to 20 μK should be possible using sideband laser cooling. The prospective clock transition is the ${}^1S_0 \rightarrow {}^3P_0$ line at 236.5 nm, a very weak electronic dipole transition induced by hyperfine mixing of ${}^3P_0$ with ${}^3P_1$ and ${}^1P_1$. We recently measured the natural linewidth of this transition to be only 1.1 Hz [1], corresponding to a line Q of 10^{15}. An excitation of the metastable ${}^3P_0$ level can be unambiguously detected as a dark period in the single-ion fluorescence signal on the cooling transition. Samples of fluorescence signal data exhibiting quantum jumps are shown in the figure. The frequency of the ${}^1S_0 \rightarrow {}^3P_0$ line coincides with the fourth harmonic of a Nd:YAG laser line. Thus an ultrastable frequency quadrupled diode-pumped Nd:YAG laser operating at 946 nm is used to probe the excitation spectrum of the ion.



Fluorescence signal of a single In^+ ion on the ${}^1S_0 \rightarrow {}^3P_1$ line, showing dark periods whenever the metastable ${}^3P_0$ level is excited.

[1] Hollemann G., Peik E. & Walther H., *Phys. Rev. A* **49** (1994) 402.

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University of Munich

PHOTON CONTROLLED STRUCTURES

Breakthroughs at Hand

The special 1994 EQEC/CLEO-Europe joint session *Quantum Engineering of Photonic Materials* as well as several presentations indicated that photon-mode control in optical microcavities and bandgap materials has made major advances recently. Claude Weisbuch (Ecole Polytechnique, Paris) reports.

During the 1994 EQEC/CLEO-Europe joint symposium, E. Yablonovitch (Los Angeles) insisted on the huge device applications which can be forecast for the emerging field of photon-mode control in semiconductor microcavities or photonic bandgap (PBG) materials [1]. Moreover, recent implementations which rely on "photonic atoms" have turned out to be easier to fabricate than those originally proposed. It is therefore not surprising that major advances [2] were reported at the 1994 EQEC/CLEO-Europe.

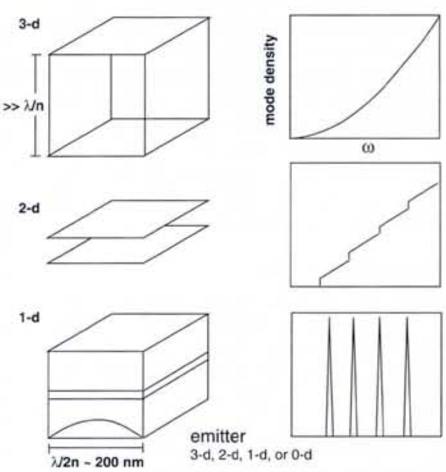


Fig. 1 — Weak light-matter coupling. Schematic illustrations (a, left) of optical microcavities with various dimensionalities of the photon modes established using localized (e.g., metallic) mirrors. Photon-mode densities (b, right) as a function of the optical frequency for each of the three types of microcavities. In the 2-d (planar) or 3-d (box-like) cavities, one or three dimensions of the cavity are of the order of the optical wavelength λ divided by the effective index of refraction n. Emission spectra correspond directly to the mode densities with, for example, sharp emission lines for 0-d cavities.

Couple-Mode Luminescence

The driving force in the the field of photon-mode control is the ability to manipulate spontaneous light emission, photon-matter interaction, beam performance, *etc. via* the selective enhancement or suppression of photon modes in wavelength-sized, post-shaped structures (microcavities) or regular structures (PBG materials). The regimes of weak and strong light-matter coupling are being investigated. In the former, the modification of light emission that can be achieved by controlling the photon modes is fully described by adjusting the photonic density-of-states (Fig. 1) and, in the case of spontaneous emission, by the resulting modification of Fermi's golden rule. In the strong-coupling regime, the interaction of a selected and enhanced photon mode with the material's excitations is so strong that the perturbation approach breaks down: the materials system and the photon-mode system interact coherently with one another, giving rise to a Rabi oscillation of the coupled photon-matter system between its two states, where one of the two systems, material or photon, is in the excited state while the other is in the ground state, and vice-versa.

C. Weisbuch (Ecole Polytechnique, Paris) described the strongly-coupled system realized by inserting semiconductor quantum wells in a planar Fabry-Perot microcavity consisting of monolithically-integrated, directly-grown, quarter-wave layer stacks of mirrors (a so-called distributed-Bragg reflector or DBR) sandwiching a spacer layer (Fig. 2a). The most recent work [3] deals with the observation and understanding of coupled-mode luminescence. The in-plane momentum dispersion curves of cavity polaritons (the coupled-mode dispersion) has been determined from a detailed analysis of the angular-resolved emission and is found to agree with the predicted curves (Fig. 2b). One therefore now understands the basic aspects of cavity-polariton emission.

There remain, however, some aspects that need further work. In particular Y. Yamamoto (Stanford and Tokyo) discussed the effects observed at high intensity with strongly-coupled semiconductor quantum wells in microcavities. He modified the usual light-matter Hamiltonian describing the photon field, the material system, and their interaction by inserting boson operators. The solution led to sidebands instead of the usual Rabi doublet, However, this attributing of luminescence sidebands to "Rabi sidebands" originating in the boson nature of the excitons is at variance with the normal fermionic behaviour of electrons in atoms.

Besides the special session, several presentations also dealt with photon-controlled structures. F. Yang *et al.* (Cardiff) reported a 25% improvement of the threshold of horizontal Fabry-Perot lasers using a planar microcavity to suppress unwanted spontaneous emission into vertical modes. Stanley *et al.* (EPF-Lausanne) demonstrated strongly-coupled multiple microcavities, whereby one couples a material system (quantum wells) with several photon-coupled microcavities. Being able to independently specify the coupling strength between the various oscillators gives a welcome handle on the concept of variable or heterogeneous coupling (the cavities, for instance, could associate different materials and functionalities).

High Efficiency LEDs

But the major issue in the field is to improve light-emitting devices (LEDs). Research is active world-wide and could soon provide a major breakthrough in the high-efficiency generation of light. One of the most desirable devices is the "zero-threshold" laser, where suppression of spontaneous emission in all photon modes but one, *i.e.*, the laser mode itself, allows continuous switching from spontaneous to stimulated emission (photon number in the remaining mode >1), with a constant quantum efficiency near unity. Additionally, the emission process would become fully deterministic, which could lead to photon emission that is limited by Johnson noise instead of the much stronger shot noise arising from the coexistence of random spontaneous emission with laser emission. De Neve *et al.* (IMEC, Gent) reported an important step towards the realization of high-efficiency LEDs, possibly zero-threshold lasers, by carefully designing a planar microcavity to give an external quantum efficiency of 6.2% (recently extended to 10.5%).

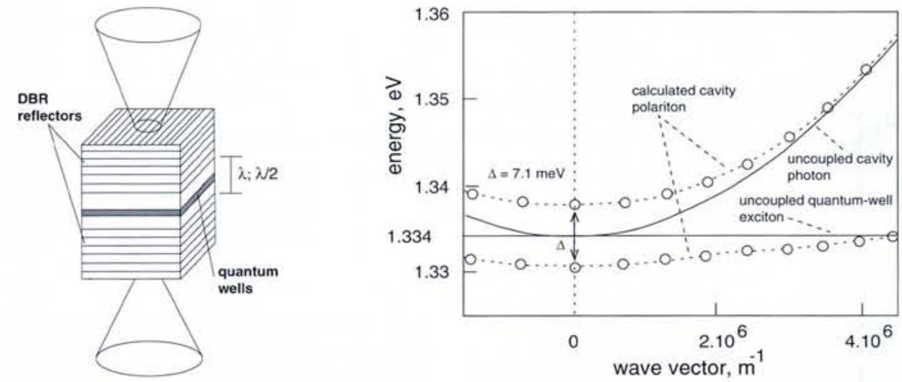


Fig. 2 — Polaritons in a planar semiconductor microcavity. a, left) Semiconductor quantum wells are inserted in a planar Fabry-Perot microcavity consisting of monolithically-integrated, directly-grown, quarter-wave layer stacks of mirrors (a so-called distributed-Bragg reflector or DBR) sandwiching a spacer layer with a thickness of λ/2 or λ. Strongly coupled behaviour arises when the cavity resonant photon mode parallel to the layers resonates with the quantum-well exciton. b, right) In-plane dispersion of the coupled exciton-cavity photon mode as determined from angular-resolved luminescence measurements. The experimental data points are accurately described by the coupled-mode dispersion (lines), the so-called cavity polariton, calculated by assuming that the excitons and the resonant cavity form a simple system of two oscillators coupled through the light-matter interaction.

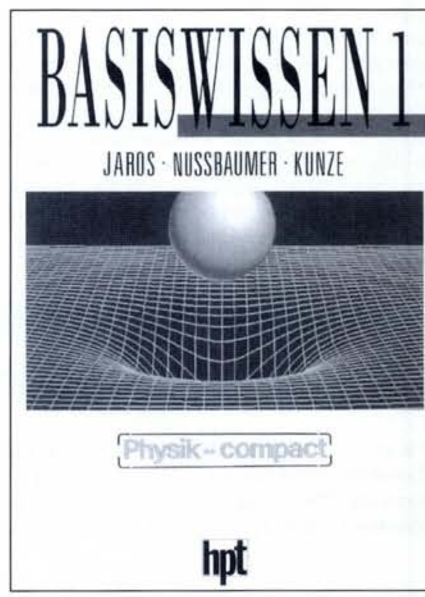
[1] Yablonovitch E., *J. Opt. Soc. Amer. B* **10** (1993) 283; *J. Mod. Optics* **41** (1994) 171.
[2] See, *e.g.*, Slusher R.E. & Weisbuch C., *Solid State Commun.* **92** (1994) 149.
[3] Houdre R. *et al.*, *Phys. Rev. Lett.* **73** (1994) 2043.

Austrian Textbook Wins Amaldi Prize

Reconciling our everyday world with the complex logical construction based on empirical principles and mathematics that allows natural phenomena to be modelled is seen by many as the challenge facing secondary school teachers. The winner of the 1993 Amaldi International Prize for a High-School Physics textbook addresses this problem by splitting the physics course into its essential parts (as four, short compact, volumes on basic knowledge) complemented by series of 12 theme-oriented books dealing with applications in daily life. The books also introduce some novel but useful devices, such as logos asking the student to do something (*e.g.*, "think about ..."), ideas for experiments for the at home, and English translations of technical terms.

The winning textbook is called *Physik-compact* published by Verlag Hölder-Pilcher-Tempsky (Vienna), Austria's largest publisher of maths and physics textbooks. The authors are Albert Jaros, Alfred Nussbaumer, Peter Nussbaumer, Hansjoerg Kunze, Leopold Mathelitsch, Robert Hofstetter, and Hans Haimo Tentchert. R. Hofstetter teaches physics and philosophy at Vienna University and in a gymnasium and L. Mathelitsch is Professor of Theoretical Physics at the Technical University, Graz. The other authors are all teachers in gymnasia, with the two Nussbaumers being twin brothers.

Physik-compact was published to coincide with the introduction of Austria's new physics curriculum in 1989, which the authors were heavily involved in defining. The four basic volumes *(Baiswissen)* are only sold in Austria, but some 1500 of the theme-oriented books *(Themenhefte)* have been sold in Germany. The Prize Jury felt the contents were flexible enough to suit curicula in different countries. This may encourage the publication of translations, for which there are no plans at present.



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The **1993 Amaldi Prize**, the first ever, was awarded by the Edoardo Amaldi Foundation, Piacenza, with EPS sponsorship. It comprised 20 000 ECU given to the authors and publishers of a high-school physics textbook first printed in Europe between 1 January 1987 and 30 September 1993. A total of 47 books were submitted out of an estimated 60-70 potential candidates, there being none in French and relatively few in German. The next prize will be awarded in a few years time.