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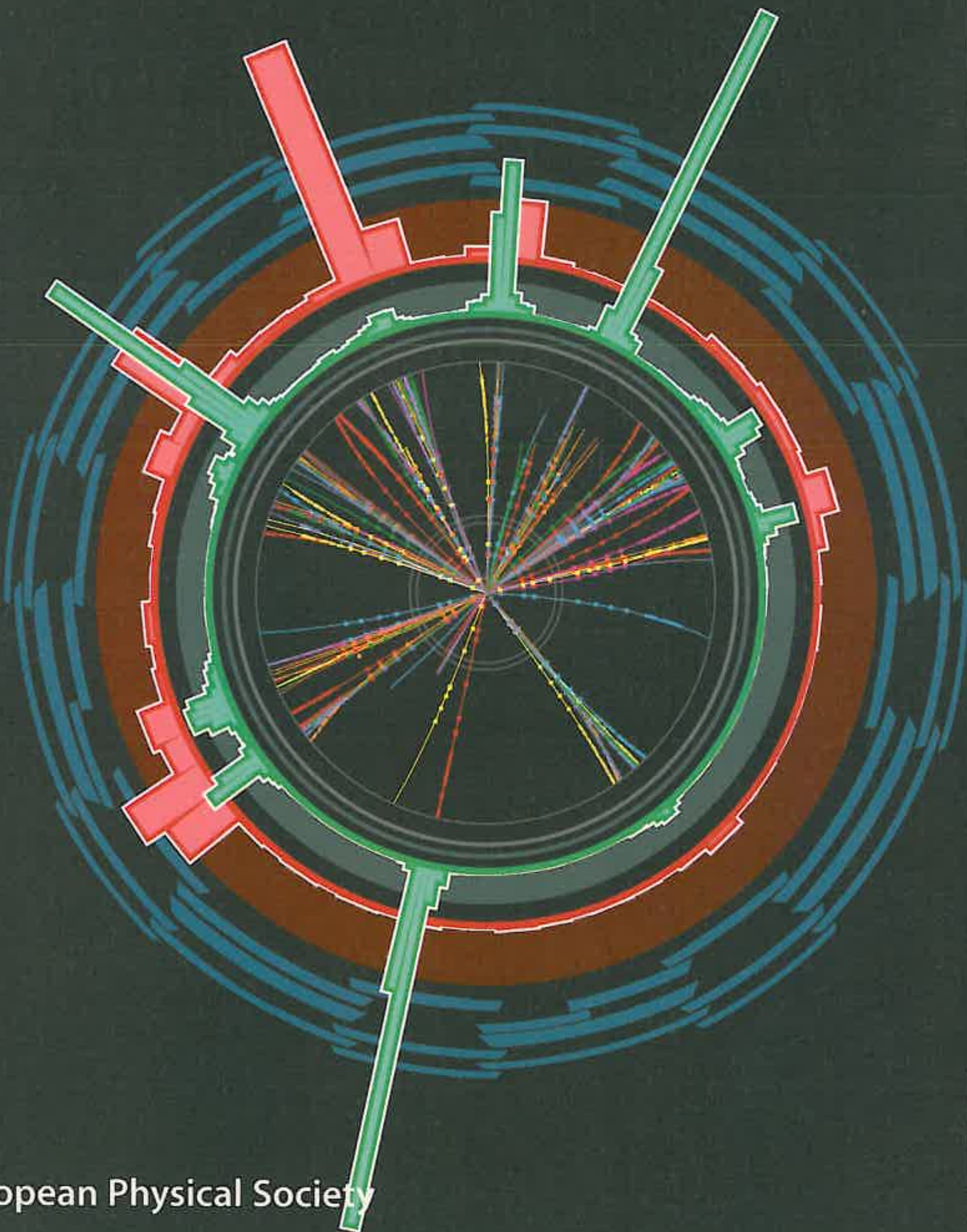

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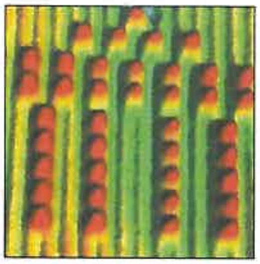

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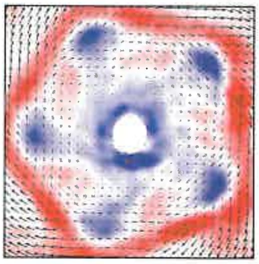

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Jupiter and Io: The unique celestial couple

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Jupiter and its satellites constitute a miniature solar system. Io, Europa, Ganymede and Callisto, the largest among the Jovian satellites are called the Galilean satellites after their discovery by Galileo Galilei in 1610. Io is the innermost Galilean satellite and according to Greek mythology Io was the dearest of Zeus (Jupiter), while the other three were also named after his lovers.

The Io-Jupiter system is unique. While Io is the most volcanically active planetary body, Jupiter is the largest planet, has the strongest magnetic field, fastest spin, biggest and most powerful magnetosphere, and has a very dense atmosphere. The study of this moon-planet system is exciting as Io is involved in active and continuous electrodynamic interaction with its parent planet. Being able to describe this system will advance our understanding of basic plasma-neutral-surface interactions, and will help us understand the behavior of interacting pairs existing at other places in our solar system and in extra solar planetary systems.

Before attempting to analyze the Jupiter-Io system, differences from the Earth-Moon system are outlined. Jupiter is 5.2 times farther from the Sun than Earth, and has an equatorial radius of 71400 km (R_J), which is 11 times that of Earth, and a volume that is 1400 times that of the Earth. The mass of Jupiter is more than the total mass of all other planets. Jupiter, with a 10-hour day, is the fastest rotator among planets. The Jovian atmosphere is mostly made of molecular hydrogen and helium with sulfur, oxygen and nitrogen in small amounts. Jupiter's magnetic moment is about 20,000 times greater than that of Earth, with magnetic field direction opposite to that on Earth and inclination of 9.6°, which is close to 11° tilt on the Earth. The general form of Jupiter's magnetosphere resembles that of Earth with dimensions about 1200 times greater.

The mass of Jupiter is more than the total mass of all other planets.

While the magnetic field of Earth is generated by the iron core, the Jovian magnetosphere is generated by the motion of magnetic material inside the liquid metallic shell. At about 1000 km below the cloud top, the hydrogen atmosphere becomes thicker and finally changes phase to become liquid hydrogen. Because of the tremendous pressure, under the liquid hydrogen layer, a layer of metallic hydrogen layer exists which causes the Jovian magnetic field. The Earth's field is reasonably well represented by a dipole but at Jupiter the quadrupole and octupole moments are significant producing a pointed and bullet shaped magnetosphere. The power for populating and maintaining the magnetosphere of Jupiter comes principally from the rotational energy of the planet and the orbital energy of Io, whereas the power source for Earth's magnetosphere is principally the solar wind.

As stated in the beginning, Io is the innermost among the Galilean satellites and is the fourth largest natural satellite in the solar system with radius of 1815 km, 2% larger than the Moon. Io orbits Jupiter at a distance of 5.9 R_J from Jupiter, which is well within Jupiter's intense magnetosphere, while our Moon is at a distance of 60 R_E (R_E is the radius of Earth) from Earth, which is well outside the Earth's magnetosphere. That means while Io constantly couples with Jupiter's magnetosphere, the Moon does not. Io is volcanically active, while the volcanoes on Moon ceased between 3-4 billion years ago. The volcanoes on Io emit an SO_2 rich material, which is one of the major sources of its SO_2 atmosphere. The Moon has a very thin collisionless atmosphere with He, Ar, Na, K, Ne etc as the constituents. Table 1 gives the important physical parameters of Jupiter and Io and a comparison with those of Earth and Moon. A detailed review on Io is presented in *Spencer and Schneider* (1996). In the present article a few of the most important issues of Jupiter-Io are addressed. Why are there volcanoes on Io? What is the role of Jupiter in producing these volcanoes? Do these volcanoes help produce an atmosphere at Io? How does this atmosphere interact with the Jovian magnetosphere and produce the torus, neutral clouds and aurora? In the following sections these fascinating questions will be discussed in order to obtain an insight into this unique planet-moon system.

▼ **Table 1:** Important physical parameters of Jupiter and Io.

Parameter	**Jupiter (Earth)**	**Io (Moon)**
Radius	71400 (6400) km	1815 (1736) km
Volume	1.4×10^{15} (1.1×10^{12}) km^3	2.5×10^{10} (2.2×10^{10}) km^3
Mass	1.9×10^{27} (6×10^{24}) kg	8.9×10^{22} (7.3×10^{22}) kg
Density	1326 (5515) kg m^{-3}	3530 (3340) kg m^{-3}
Gravitational acceleration	23.1 (9.8) m s^{-2}	1.8 (1.6) m s^{-2}
Escape velocity	59.5 (11.2) km s^{-1}	2.5 (2.4) km s^{-1}
Orbital period	4330 (365) days	1.7 (27) days

The Jovian system has been visited by a number of spacecrafts: Pioneer 11 and 12, Voyager 1 and 2, Ulysses, Galileo and most recently by Cassini. Pioneer 11 and 12 arrived at the Jovian system in 1973 and 1974, respectively, while Voyager 1 and 2 have visited Jupiter and its satellites in 1979. The Ulysses is the first spacecraft to explore interplanetary space at high solar latitudes whose encounter with Jupiter occurred in 1992. The Galileo spacecraft has been orbiting around Jupiter since 1995 and in December 2000 the Cassini spacecraft passed through the edge of the Jovian magnetosphere.

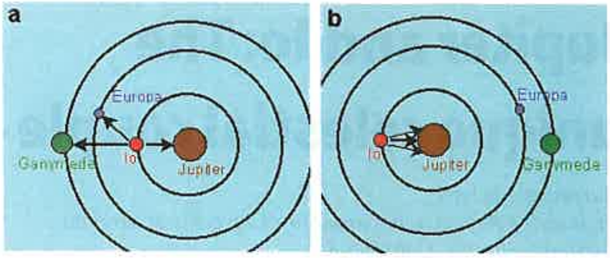
Volcanism and internal structure of Io

***Volcanic activity*:** Io is the only body outside the Earth, to exhibit active volcanism on a massive scale. It can provide a picture of active volcanic processes that ceased elsewhere in the solar system. The volcanism on Io was discovered by the Voyager spacecraft in 1979. The recent observations of this amazing body by the Hubble Space Telescope (HST) and the Galileo spacecraft have shown that Io is dotted by hundreds of volcanic centers. Volcanic activity on Io is so relentless that there are no signs of impact craters on its surface, as they are rapidly filled in with volcanic material soon after they are formed. The extensive volcanic activity on Io generates dramatic changes to it's surface over very short timescales. Volcanic material is ejected with speeds of 1 km s^{-1}, which is nearly half the required escape velocity on Io, compared to the 100 ms^{-1} ejecta speed for volcanoes on Earth. The higher ejection speed combined with the lower gravity gives volcanic plumes up to 300 kilometers above the surface of Io. These eruptions closely resemble geysers on Earth. The recent observations showed that the temperature of the hot spots on Io ranges up to 2000 K. Such lavas were common in the early history of the Earth (~2.0 to 4.5 billion years ago) when the Earth's internal heat content was much greater.

The heat source that produces volcanic activity on Earth is the energy released from the decay of radioactive materials within the interior, as well as from heat left over from Earth's formation. But tidal heating produced by Jupiter and the other Galilean satellites is responsible for the massive volcanism on Io. Being an enormous planet, Jupiter exerts a tremendous gravitational force on Io, which orbits relatively close to the giant planet. The relative closeness is seen by comparing the orbital distances of moon and Io from their respective parent planets. As stated in the beginning, Io orbits Jupiter at a distance of 5.9 R_J while Moon's orbit is 60 R_E from Earth. Any object placed in the gravitational field of another will experience forces that tend to distort it, because the attraction is stronger on one side than on the other side. If the body is liquid, it will assume a somewhat elongated shape with the long axis pointed toward the gravity's source. If the body is rigid, it will gradually assume a stable elongated shape and becomes phase locked to the parent planet. However, if the gravitational field changes the body will flex in response. This flexing produces friction and heat inside the body. This is what is happening at Io. Although Io is phase locked to Jupiter, it is in orbital resonance with Europa and Ganymede (for every orbit of Ganymede, Europa makes two and Io makes four orbits). Jupiter pulls Io inward toward itself, while the gravity of the outer moons pull it in the opposite direction. A cartoon explaining this pull by Jupiter and the other satellites is shown in Figure 1. At one point of time Jupiter is at one side of Io and the other satellites are on the other side as in Figure 1a. Later Jupiter and the other satellites are on the same side of Io as in Figure 1b. As a result, Io is subjected to varying tidal forces that cause Io's solid surface to bulge up and down as much as 100m, while the ocean tides on Earth have average excursions of the order of 10m. This friction generates enormous amounts of heat and pressure within Io, causing molten material and gases to rise through fractures in the crust and to erupt onto the surface.

...extensive volcanic activity on Io generates dramatic changes to it's surface

Figure 2 is a picture of Io in enhanced color taken by Galileo. The surface colors are due to the volcanic activity and the subsequent lava flow. Sulfur gas (S_2) was recently detected above one of the Io's volcanoes by the Hubble Space Telescope (HST). This compound is stable at the very high temperatures inside the volcano, but once it is ejected and lands on the cold surface, the sulfur atoms rearrange themselves into larger molecules of three or four atoms (S_3 and S_4), which give the surface a red color. Eventually the sulfur atoms rearrange themselves into their most stable configuration (S_8), which is yellowish in color. SO_2 frost explains the presence of the white patches. The recent observations of high temperature lava suggest the presence of silicates, which are confirmed by the presence of Mountains.



▲ Fig. 1: (a). Jupiter is on one side of Io while Europa and Ganymede are on the other side and Io is pulled from both sides. 1(b). Jupiter, Europa and Ganymede are on the same side of Io and is pulled to the same side.

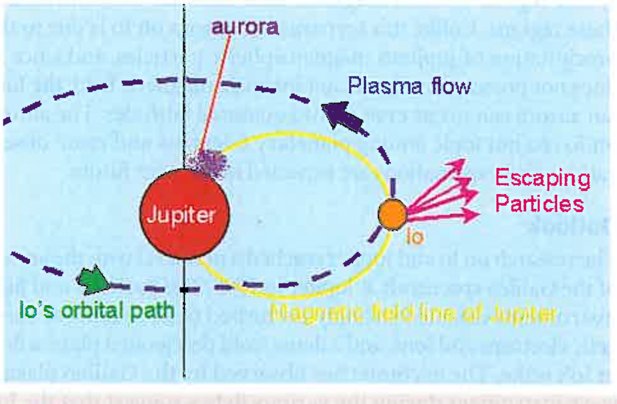
▲ Fig. 2: The enhanced color image of Io taken by Galileo spacecraft in 1996 (http://galileo.jpl.nasa.gov).

Internal structure: The gravity-field measurements taken by the Galileo spacecraft have shown that the interior of Io is gravitationally separated. That is, dense materials while in the molten state sink to the center of the satellite to form the core and less dense elements rise toward the surface. Io is believed to have a dense core composed of iron and iron sulfide with a radius of approximately 900 km, which extends about halfway to the surface. It is likely that the core is formed either from internal heating processes during the early stages of the moon's formation, or as a result of the ongoing tidal heating that drives the volcanic activity at the surface. Surrounding the core is a mantle of partially molten rock, which is overlain by a relatively thin, rock crust. The *Journal of Geophysical Research*, volume 106, issue E12, December 25, 2001 has provided a special section on the geology and geophysics of Io including the latest observations.

Atmosphere of Io

The nature of an atmosphere on Io has been of interest ever since the discovery of an ionosphere by the Pioneer spacecraft in 1973. SO_2 is the major constituent in the atmosphere of Io, and was observed in infrared by Voyager, in ultraviolet by HST and Galileo, and in millimeter wave by ground-based observations. SO has been observed in the millimeter wave by its rotation lines and S_2 in ultraviolet. The photochemical products of SO_2, Na, K, Cl, and NaCl are also present in Io's atmosphere. The sources of SO_2 in the atmosphere of Io are volcanic activity, sunlit sublimation of surface SO_2 frost, and sputtering. The major sources are the first two, but the relative importance is poorly understood.

Io's atmosphere is observed to be patchy and time variable. This property of the atmosphere supports the concept of volcanic origin. Volcanoes produce localized atmospheres with pressures that decrease rapidly with distance from the source. Sublimation

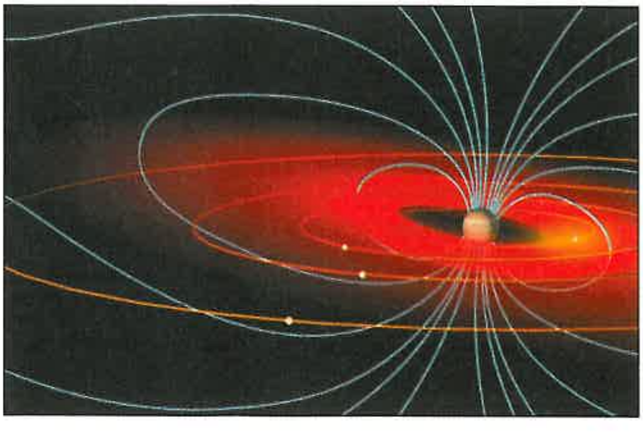


▲ Fig. 3: Schematic of Io Jupiter system. The magnetic field line of Jupiter, which passes through Io, is the Io flux tube (IFT). The escaping particles which are ionized travel with the magnetic field lines around Jupiter and forms the Io plasma torus as in figure 4 and those which are not yet ionized form a neutral cloud as shown in figure 5.

of SO_2 frost is responsible for the existence of a more distributed atmosphere. Although the sublimation atmosphere can reach the nightside, volcanoes are a direct source of the atmosphere on the night side where the temperatures are very low. Surface sputtering is considered the least important source of atmosphere. Energetic ions which reach Io's surface can cause the ejection (sputtering) of molecules from the surface. Though sputtering is not very efficient in producing an SO_2 atmosphere, it might be important for ejecting more refractory species such as Na to be discussed below. A detailed review about the atmosphere of Io is given in *Lellouch* (1996) and the latest atmospheric model is discussed in *Moses et al.* (2002).

Jovian magnetosphere, Io torus and neutral clouds

Since Io resides in the magnetosphere of Jupiter, ions of sufficient energy on colliding with Io's atmospheric species transfer their energy to the atmospheric particles. These particles can then escape from the atmosphere of Io if they get energy greater than the escape velocity. A schematic plan of the escape of particles from the atmosphere of Io is shown in Figure 3. Particles escape at a rate of 1000 kg s^{-1} from the atmosphere of Io. Some of these escaping atoms and molecules become ionized and are therefore trapped by the Jovian magnetic field lines, which drag them along. These ions form a doughnut-shaped region along the orbit of Io around Jupiter known as the Io plasma torus, which is shown in red color in Figure 4.



The torus is populated with sulfur and oxygen ions, which are the photochemical products of SO_2 with sodium, potassium and chlorine ions in trace amounts. As the orbital velocity of Io is less than the rotational velocity of the Jovian magnetospheric plasma the Jovian field lines and the associated plasma stream past Io at a relative speed of 57 km s^{-1}. This flow sets up a potential difference of ~400 kV across Io resulting in a current of ~10^6 A that closes through the Jovian and Ionian ionospheres. The magnetic field lines which connect Io to Jupiter define the Io Flux Tube (IFT) which is the yellow line connecting Jupiter and Io in figure 3. The ejected gas from Io, which has not yet been ionized, forms a huge atmosphere near Io known as the neutral cloud. Figure 5 shows an image of the Na component of the cloud, which is connected with Io as it orbits Jupiter. In this figure Io is represented by the small dot inside the crossbars. Clouds of neutral oxygen, sulfur and chlorine also are present. Although the density of sodium is very small, it is easy to detect (Figure 5) due to the strong resonant scattering, when illuminated by sunlight, of the yellow sodium D lines.

Auroral emissions from Jupiter and Io

Electromagnetic radiation emanating from the polar regions of a planet is known as aurora. These auroral emissions are generally produced by the excitation of the upper atmospheric atoms and molecules by energetic electrons and ions precipitating down from the planet's magnetosphere. The occurrence of aurora is a topic of its own and a meticulous review on the aurora of the outer planets is given in *Bhardwaj and Gladstone* (2000).

The aurora at Jupiter is very interesting as it hosts a variety of different kinds of auroral processes from that on Earth. Here we restrict our discussion to the auroral processes at Jupiter, which are associated with Io. Aurora spot like emissions were observed at Jupiter where the Jovian magnetic field lines that pass through Io touch Jupiter's atmosphere. These spot like emissions are called Io flux tube footprints and is a direct signature of the complex electrodynamical interaction between Io and Jupiter. The first direct evidence of the Io Flux Tube (IFT) footprint was obtained in a near infrared (H_3^+) image of Jupiter's emission at 3.4 μm in 1992 by ground based observation. The H_3^+ ion is formed in Jupiter's auroral ionosphere by the ionization of H_2 by an electron or an ion followed by conversion to H_3^+. This H_3^+ ion is vibrationally excited and returns to the ground state by emitting the near infrared radiation of 3.4 μm. The ultraviolet IFT footprints were first detected by HST in 1994 in the H_2 Lyman and Werner bands. These emissions are produced by the collisional excitation of the atmospheric H_2 molecules by precipitating charged particles. The IFT footprint in the visible region was observed for the first time by Galileo spacecraft in 1998. Figure 3 shows the auroral radiation from Jupiter where the Io flux tube touches Jupiter.

The Jovian magnetospheric plasma also produces emissions from Io. Spectacular emissions were observed from Io in visible, ultraviolet and x-ray wavelengths. Emissions in the visible were observed by Voyager, ground-based telescopes, Galileo, HST, and Cassini. The first observations by the Voyager 1 spacecraft occurred in 1979. The ground based telescopes have been observing

◀ Fig. 4: Jupiter, Io, Europa, Ganymede and Callisto. The satellite on the right side of Jupiter is Io. The doughnut-shaped red structure along the orbit of Io around Jupiter is the Io plasma torus. The blue lines are the magnetic field lines of Jupiter. This cartoon was prepared by *John Spencer* of Lowell Observatory.

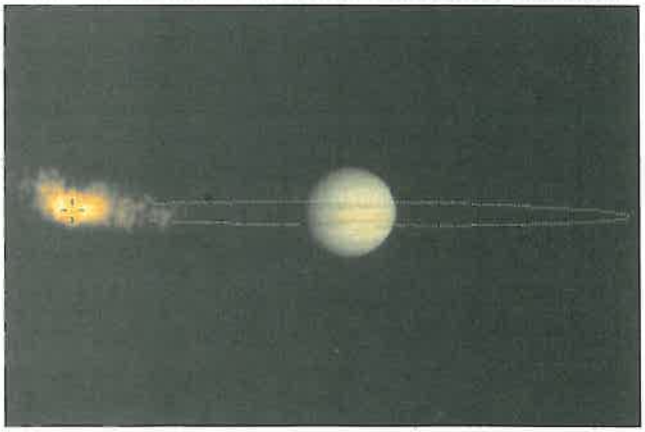
features

the neutral oxygen emission at 630 nm from Io since 1990. Galileo spacecraft detected visible emissions in the blue (380-440 nm), green (510-605 nm) and red (615-710 nm) band, which appeared to be correlated with Jovian magnetic field orientation at Io. The blue emissions were observed close to the equator, the red emission along the limb and the green emissions were concentrated on the night side. The probable sources of these emissions are SO_2 bands in the blue region, oxygen lines of 630 and 634 nm in the red region and oxygen line of 557.7 nm and sodium lines of 589 and 589.6 nm in the green region. Cassini has observed visible emissions from Io in late 2000 and early 2001 on its way to Saturn. The wavelength filters used in the Cassini spacecraft range from 235 to 730 nm.

Ultraviolet emissions from Io were observed for the first time in the late 1980's. In the early 1990's HST observed neutral oxygen and sulfur emissions in the ultraviolet region. The important line emissions among them are oxygen lines at 130.4 nm and 135.6 nm and sulfur lines at 147.9 nm and 190 nm. The spatial structure of these emissions were studied in detail by the Space Telescope Imaging spectrograph onboard HST in 1997. These observations have shown that Io's UV emissions are correlated with the orientation of the Jovian magnetic field near Io suggesting the role of magnetospheric plasma in producing these emissions. A detailed study of the interaction of Jovian magnetic field-aligned electrons with the atmosphere of Io producing these emissions is given in *Michael and Bhardwaj* (2000) and *Saur et al.* (2000).

Ultraviolet emissions from Io were observed for the first time in the late 1980's.

X-rays from Io were observed by the Chandra x-ray observatory in 1999 and 2000. These emissions are suggested to be produced due to the bombardment of Io's surface by hydrogen, oxygen and sulfur ions of energies greater than 10 keV. Aurora on planets like Jupiter and Earth are produced due to the precipitation of charged particles from the planet's magnetosphere to the upper atmosphere and are mostly confined to the high latitudes (polar regions), as the magnetic field lines are concentrated at these regions. Unlike this scenario, the aurora on Io is due to the precipitation of Jupiter's magnetospheric particles, and since Io does not possess any significant intrinsic magnetic field, the Ionian aurora can occur even at the equatorial latitudes. The aurora on Io is a hot topic among planetary scientists and more observations and explanations are expected in the near future.



▲ Fig. 5: The image of Io's neutral sodium cloud seen from Earth shown together with Jupiter and a schematic drawing of Io's orbit to scale. The location and size of Io is indicated by the orange dot within the cross bars (Goldberg, B.A. et al. *Science*, vol. 226, p.512, 1984)

Outlook

The research on Io and Jupiter reached a new level with the arrival of the Galileo spacecraft at Jupiter in 1995. The particles and field instruments detected strongly perturbed fields, beams of energetic electrons and ions, and a dense, cold decelerated plasma flow in Io's wake. The asymmetries observed by the Galileo plasma wave instrument during the various flybys suggest that the Io's ionospheric plasma density is being strongly influenced by the magnetospheric plasma flow around Io. Detection of emissions at the Io footprint in Jupiter's auroral atmosphere in the infrared, ultraviolet, and visible wavelengths revealed that the particles associated with Io reach Jupiter. The *Journal of Geophysical Research*, volume 106, issue A11, November 1, 2001 has given a special section on the studies of Io including the latest results from the Galileo spacecraft. Two spacecrafts, Cassini and Galileo were in the vicinity of Jupiter in the early 2001, which is the first ever conjunction of two spacecrafts at an outer planet. Observations of these two spacecrafts were complemented by nearly simultaneous images from the Earth orbiting Hubble Space Telescope and Chandra X-ray observatory. The results of all these observations are reported in various papers in the issue of *Nature*, volume 415, February 28, 2002.

An analogy of the Io-Jupiter system is now being applied to extra-solar planets and binary stars consisting of magnetic and non-magnetic white dwarfs. More importantly the vibrant volcanism and extreme heat flow of Io may help us understand the early stages of Earth. The study of this exciting system is attracting young scientists from a broad range of disciplines and our understanding is advancing swiftly.

Acknowledgement

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Organic-inorganic hybrids—the best of both worlds?

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Man has been exploiting the properties of both inorganic and organic substances for millennia, whether it be in the pottery of ancient civilisations or the pharmaceutical properties of plant extracts. The ancient Greeks regarded these as very different, the pottery being of mineral origin and the plant being vegetable. This distinction has survived largely unscathed until relatively recently, with the two types of materials generally displaying radically different properties and finding quite different applications. While the attractions of combining, for example, an inorganic glass with an organic polymer on a molecular level are manifold, it is equally self-evident that the conditions required for processing a glass are entirely incompatible with the much lower processing temperatures needed for polymers. This all changed with the realisation in the 1980s that organic components could be combined with inorganic glasses using the *sol-gel process*. Around the same time, various research groups were exploring routes to combining polymers with clay minerals to produce different types of *organic-inorganic hybrids*. This area has flourished in the past 20 years or so and this article will highlight some of the advances made by us and others in recent years.

The rationale behind all this activity is the unique combination of properties accessible via a hybrid approach. For example, a polymer can be modified by the inorganic component to provide improved thermal and mechanical properties. Alternatively, polymer-modification of a glass or ceramic can introduce improved flexibility and processability. In principle, an infinite number of combinations is possible, although this is limited in practice by processing considerations. Other benefits include the possibility of incorporating an active organic component within a porous glass to produce an active glass such as a sensor. Isolation of active organic species within an inorganic matrix can also have implications for the behaviour of, and interactions between, the organic molecules. An interesting example of this is sol-gel silica entrapped bacteria (Fig. 1), where communication (quorum sensing) between individual bacteria is hindered by the matrix [1].

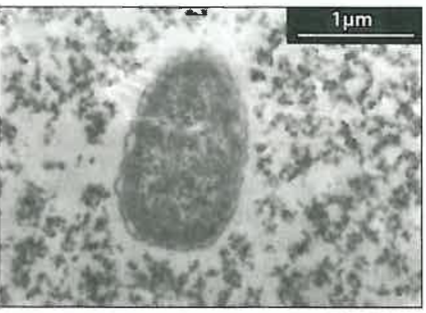


Fig. 1: Electron micrograph of an isolated bacterium trapped within a sol-gel silica matrix. [Reprinted by permission from Nature Materials (N Nassif *et al., Nature Materials*, 2002, **1**, 42-44) copyright (2002) Macmillan Publishers Ltd.]

Nanomaterials

Many of these hybrids are examples of *nanomaterials* [2], where one or more component phases exists on a nanometre scale (< *ca.* 100 nm). There has been much hype about nanomaterials, creating an impression that they are a panacea for all technical ills; the reality may sometimes be quite different, leading to a degree of creeping cynicism. In the context of organic-inorganic hybrids, a key question is whether it really matters whether they are true nanocomposites or not. For some applications (e.g. sensors), this can result in a transparent hybrid, which may be highly desirable. In terms of the effect of nanoscale morphology on mechanical properties of polymer hybrids, the existence of a large number of interfaces and consequently high interfacial area in comparison to conventional filled polymers leads to the potential for energy absorption and subsequent system toughness, although this has yet to be fully realised. Although it has been claimed that nanofillers can lead to highly rigid and strong composites, work to date has indicated that in many cases, the resultant nanocomposites behave as expected for more conventional microcomposites, such as fibre-reinforced polymers. For example, in the case of nanocomposites consisting of clay platelets dispersed in a polymer matrix (so-called exfoliated systems), certain mechanical properties such as modulus have been found to follow the classical Halpin-Tsai model for composite behaviour (equations 1 and 2). The key parameter is the aspect ratio of the clay platelets, which behave in a similar way to short glass fibres of comparable aspect ratio (represented in the equations by the shape factor, ξ).

$$\frac{E_c}{E_m} = \frac{(1+\xi\eta V_r)}{(1-\xi\eta V_r)} \qquad \textit{Equation 1}$$

and

$$\eta = \frac{(E_f - E_m)}{(E_f + \xi E_m)} \qquad \textit{Equation 2}$$

E_c = composite modulus (stiffness)
E_m = matrix modulus
E_f = fibre modulus
V_r = volume fraction of reinforcing phase
ξ = shape factor

Clay nanocomposites

There are two kinds of clay nanocomposites (Figure 2), which are referred to as either intercalated or exfoliated, depending on the degree of separation of the individual clay platelets. Note that although the figure shows the platelets as rigid entities, in reality they have some flexibility which means they may not be linear in the composite. The main approaches to preparing these nanocomposites initially require the platelets to be made 'organophilic', by exchanging the interstitial metal ions with a charged organic species such as a cationic surfactant. This aids penetration of organic species into the interstices and subsequent interlayer expansion and eventual exfoliation. Preparative routes include the use of solvent blending of the polymer with the clay, *in situ* polymerisation of monomer precursors on the clay and melt blending of the polymer and clay. Whether an intercalated or exfoliated structure is formed depends on the synthetic method used and other factors, such as the nature of the clay. The presence of clay platelets in the polymer leads to a number of possible applications, including gas barrier products and fire retardant materials. One rationale behind these properties is the so-called

features

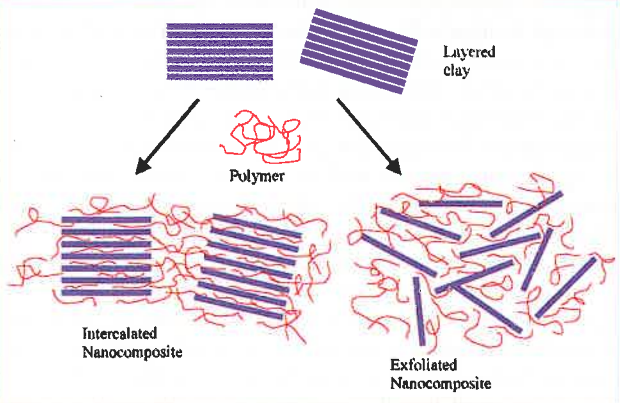
tortuous path imposed by the clay platelets on molecules moving through the polymer. An interesting example of the barrier application is work by the US Army to develop impermeable food containers for long term use in the field.

The optical properties of nanocomposites have attracted much interest, particularly their transparency and 'active' optical properties. Transparent products can be obtained from layered systems under certain conditions. Hybrids of clay and nematic liquid crystals exhibit interesting electro-optical properties. These materials can be transparent (Figure 3, a) or opaque (Figure 3, c) depending on the frequency of the applied electric field[3]. The effect is reversible and can be repeated many times. The transparent and opaque states exhibit a memory effect after switching off the field (Figure 3, b and d). Such materials have potential applications in optical storage devices, displays and light-controlling glass. Poly(*p*-phenylene vinylene)s have been studied extensively for their electroluminescence and potential applications in light emitting diodes (LEDs). The synthesis of intercalated hybrids of smectic clay and a substituted poly(*p*-phenylene vinylene) has been reported—these hybrids exhibit electroluminescence and the luminescence appears to be colour tunable depending on the degree of intercalation.

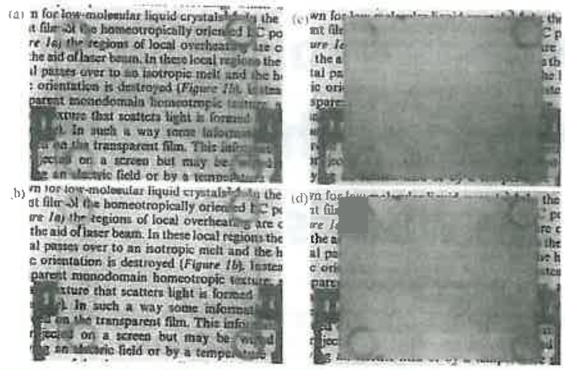
The optical properties of nanocomposites have attracted much interest

Sol-gel hybrids

The main alternative to the clay route for the formation of organic-inorganic hybrids is the sol-gel process. This is a low temperature route to inorganic oxides and glasses, which involves the hydrolysis and condensation of precursor molecules, typically alkoxides. The reaction proceeds *via* formation of a *sol*, which subsequently *gels*, hence the name. The fact that this process occurs at temperatures between ambient and about 200°C makes it possible to form a vast array of hybrids of oxides such as silica, alumina and titania with organic species ranging from polymers to small organic molecules to bacteria (Figure 1). The products can also be produced in a variety of physical forms, including coatings, monoliths, fibres and nanoparticles. The many potential applications of such sol-gel hybrids include speciality coatings, structural materials, active glasses, sensors, biomaterials, catalysts and so on. An article of this nature can barely scratch the surface of this vast topic, so the versatility of sol-gel science will be illustrated with reference to only two areas, *viz.* sensors and biomimetics.

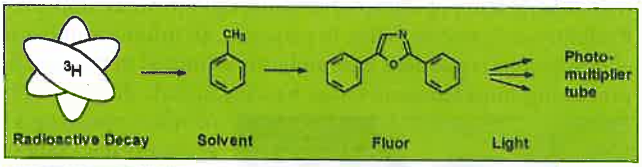


▲ **Fig. 2:** Formation of polymer-clay nanocomposites.



▲ **Fig. 3:** Electro-optical properties of clay-nematic liquid crystal hybrids: (a) low frequency, on; (b) low frequency, off; (c) high frequency, on; (d) high frequency, off. [Reprinted from Materials Science & Engineering C, Vol 6, Kawasumi *et al.*, 'Nematic liquid crystal/ clay mineral composites', pp 135-143, Copyright (1998), with permission from Elsevier].

Some of the benefits of using sol-gel hybrids as sensors are illustrated by patented work on radioactivity sensors undertaken at the University of Surrey. Detection and quantification of radioactivity in liquids is important in situations such as accidental spills into watercourses. Well-publicised cases of contamination of streams by tritiated water (tritium is a β emitter) illustrate the problem. The conventional approach to measuring this radioactivity involves addition of a so-called liquid scintillation cocktail (Figure 4) to the liquid. Energy transfer occurs from the radioactivity emitted by the radionuclide *via* the solvent to a small molecule which acts as a fluor, *i.e.* emits light which can then be 'counted'. Because the measurement is done by mixing this scintillation cocktail with the liquid whose radioactivity is to be measured, the process of making the measurement increases both the volume and complexity of the radioactive liquid tested and hence the radioactive waste to be disposed of.

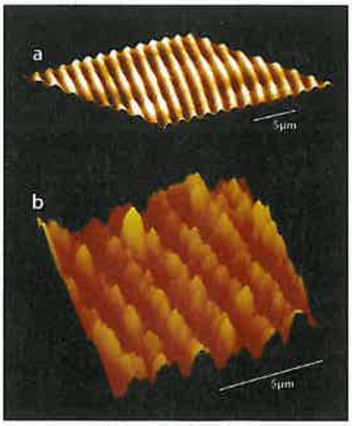


▲ **Fig. 4:** Schematic representation of radioactivity detection by liquid scintillation counting.

We sought to develop efficient, durable radioactivity sensors which could be used in flow systems without increasing waste production. Using sol-gel methods, the fluor can be either encapsulated or covalently bonded within a porous silica glass [4]. The products are transparent, an important consideration for sensing applications. Surprisingly, the efficiency of the radioactivity detection is hardly impaired by incorporation of the fluor in the glass. While the encapsulated system suffered from leaching of the fluor, this drawback was overcome by the simple expedient of bonding the fluor to the glass. The ready formation of the hybrid at low temperatures means that these sensors can be applied to the coating of glass tubes, capillaries, *etc.*, leading to use in flow systems and other product forms. This approach thus provides a relatively simple route to the manufacture of efficient and durable sensors and can be adapted in principle to a wide range of other types of sensor. For example, a similar hybrid approach has been used in the development of gas sensors.

Biomimetics

One area which is generating considerable excitement at present is biomimetics, where an increasing understanding of the clever 'tricks' used by Nature to produce its awesome range of biomaterials (*e.g.* bone) is inspiring scientists to copy and adapt these approaches in an effort to produce synthetic materials with a comparable range of properties. A subset of biomimetics is biomineralisation, where various biomolecules catalyse and direct the synthesis of inorganic networks to produce hybrids structures of often stunning complexity and beauty. Examples include the calcium carbonate or silica based shells of marine organisms such as coccoliths, abalone and diatoms. In the case of diatoms, research in both the USA and Germany has shown that specific proteins (silaffins) play a prominent role in controlling the growth of silica structures involving assembly of silicic acid molecules found naturally at low concentrations in sea water [5]. The knowledge of these protein structures has prompted the development of synthetic proteins and other polymers which catalyse silica formation under mild conditions. Steve Clarson and co-workers [6] at the University of Cincinnati and the US Air Force Research Laboratory have reported an elegant demonstration of the extension of this idea to the formation of novel holograms. Using a holographic photopolymerisation technique, they were able to make a polymer hologram containing a synthetic peptide similar to the silaffins. This hologram was able to catalyse subsequent formation of silica nanospheres from silicate precursor to form a hologram with the silica spheres in a regular 2-dimensional array. The atomic force micrographs show the surface features of the parent polymer hologram and the silica-polymer hybrid (Figure 5) The hybrid hologram showed a much higher diffraction efficiency than the polymer hologram. Not only does this work illustrate the use of this kind of biomimicry in nanopatterning, it also demonstrates the potential for rapid transfer of a fundamental understanding of natural processes into high tech, practical applications.



◄ **Fig. 5:** Atomic force micrographs of a polymer hologram (a) and the corresponding silica-polymer hybrid (b). [Reprinted by permission from Nature (L L Brott *et al.*, *Nature*, 2001, **413**, 291-293) copyright (2001) Macmillan Publishers Ltd.]

Conclusion

The relatively recent advances in the preparation and evaluation of organic-inorganic hybrids has opened up huge opportunities for the development of unique materials, exhibiting a range of properties rarely seen in other types of material. Starting from existing materials and precursors, scientists have the opportunity to produce a vast array of new materials with tailored properties for a wide range of applications, both in conventional markets and in new 'high tech' areas. Within the UK, a government funded network on 'Organic-Inorganic Hybrids for Structural and Semi-Structural Applications' [*HybridNet*] has been established since June 2001 with the aim of promoting and aiding the exploitation of hybrids within UK academia and industry. The network has about 30 member organisations and is coordinated by one of the authors (JNH). This and other initiatives are likely to accelerate the growth of this technology, such that we may truly be entering 'the age of the hybrid'.

About the authors

Professor John Hay, CChem, FRSC, CPhys, FInstP, joined the University of Surrey in 1994 following nearly 14 years in industry, firstly at the BP Research Centre and then in the Research Laboratory of Kobe Steel Europe. He became Professor of Materials Chemistry in 1999 and DERA (now QinetiQ) Professor of Materials Chemistry in 2000. His work has been concerned primarily with the synthesis, characterisation and applications of polymers, composites and organic-inorganic hybrids, as well as the use of supercritical fluids in polymer processing.

Professor Steve Shaw, PhD, FIM, CPhys, FInstP, is currently Technology Chief for Polymers and Adhesives within the Future

Glossary of Terms

Polymer: A large molecule (macromolecule) consisting of many smaller repeating sub-units linked together. Commonly used to refer to organic materials of this nature.

Monomer: The molecules which link together to form the sub-units of a polymer.

Ceramic: Traditionally used to describe a material produced from fired clay and used in the manufacture of pottery. Also used to describe a non-organic, non-metallic substance, often an oxide.

Clay: Sheet-like aluminosilicate minerals, where the negatively charged layers are held together by interstitial cations. Often found in sedimentary deposits.

Glass: An amorphous inorganic oxide or mixed oxide, commonly referring to silicate glasses, but more generally applicable to solids exhibiting a softening point (glass transition).

Sol: A colloidal suspension of small (*ca.* 1-1000 nm), often charged, particles in a liquid such as water.

Gel: A three-dimensional network of a polymer or inorganic oxide, which is normally highly porous and contains a substantial proportion of a liquid. In the sol-gel process, the inorganic oxide sol particles link together to form the gel.

Aspect ratio: The ratio of length to width for an elongated species such as a fibre.

Cationic surfactant: A soap-like molecule which commonly consists of a long non-polar 'tail' attached to a positively charged 'head' group.

Nematic: A type of phase found in liquid crystals. The rigid molecules are orientated parallel in one dimension, but with no specific order in the other dimensions.

Systems Technology Division at QinetiQ, Farnborough. His current research activities include pre-bonded surface treatments for various material types, development of 'smart' adhesives, ultra-high temperature polymers and organic-inorganic hybrids. He is a QinetiQ Fellow and a Visiting Professor at the University of Surrey.

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Why are insulators insulating and metals conducting?

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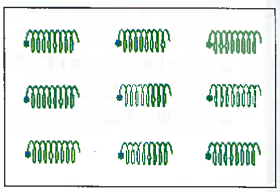
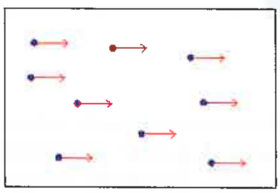
An insulator is distinguished from a metal by its vanishing dc conductivity at low temperature. In contrast to what happens in metals, the electronic charge in insulators (and quite generally nonmetals) cannot flow freely under an applied dc field, but instead undergoes static polarization. Within classical physics, this qualitative difference is attributed to the nature of the electronic charge, as sketched in Fig. 1: either "bound" (Lorentz model for insulators) or "free" (Drude model for metals). In other words, electrons are *localized* in insulators and *delocalized* in metals. Switching to quantum physics, this clearcut distinction is apparently lost. In most textbooks [1], the insulating/metallic behaviour is explained by means of band structure theory, focussing on the position of the Fermi level of the given material: either in a band gap (insulators), or across a band (metals), as in Fig. 2.

Why do we need a theory of the insulating state different-and formally more complex-than the familiar one sketched in Fig. 2? The point is that such a picture applies only to a crystalline material, within the independent-electron approximation [1]: a very limited class of insulators indeed. In some materials the insulating behaviour is dominated by disorder (Anderson insulators), in some it is dominated by electron correlation (Mott insulators): therefore, for a large number of insulators, the band picture is grossly inadequate. The present theory of the insulating state [2, 3, 4] deals with *all* kinds of insulators on the same basis: either crystalline or disordered, either independent-electron or correlated.

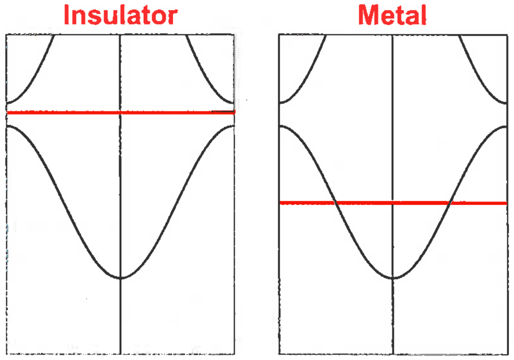
The insulating/metallic state of matter is characterized by the excitation spectrum, but the qualitative difference in dc conductivity must also reflect a qualitative difference in the organization of the electrons in their *ground state*: a concept first emphasized by W. Kohn in a milestone 1964 paper [5]. Its outstanding message is that even within quantum mechanics the *cause* for insulating behaviour is electron localization. Such localization, however, manifests itself in a very subtle way: in fact the electrons in a condensed system appear, from several viewpoints, about equally delocalized in nonmetals and metals. For instance, the Bloch orbitals in either crystalline silicon or crystalline aluminum are similarly delocalized, and do not reveal any sharp difference. The challenge is to show how electron localization can be detected and measured in the ground wavefunction of a condensed many-electron system. The difference between localized and delocalized must be, in the thermodynamic limit, a sharp one. A solution to this problem was provided by Kohn in his original 1964 paper. In 1999 the problem was reconsidered and a solution different from Kohn's-and in many respects simpler-was found [3].

There is an outstanding phenomenological link between macroscopic polarization and the insulating state of matter. Suppose we expose a finite macroscopic sample to an electric field, say





◀ **Fig. 1:** Schematic view of insulators and metals in classical physics. Top sketch: Lorentz model for insulators, where each electron is tied (by an harmonic force) to a particular center. Bottom sketch: Drude model for metals, where electrons roam freely over macroscopic distances, hindered only by atomic scattering potentials.



▲ Fig. 2: Traditional textbook view of the qualitative difference between insulators and metals. The plots show the energy band structures of crystalline (i.e. ordered) materials, chosen one-dimensional for the sake of simplicity. The insulating/metallic behaviour depends on the position of the Fermi level, which in turn is determined by the number of electrons per cell. A filled band results in insulating behaviour, while an half-filled one results in metallic behaviour. For many insulating materials (e.g. disordered and/or correlated) such a band picture is inappropriate. The present theory of the insulating state is based on quite different concepts, and applies on the same grounds to *any* insulator.

inserting it in a capacitor and applying a voltage. Then the induced macroscopic polarization is qualitatively different in metals and insulators. In the former materials polarization is trivial: universal, material-independent, due to surface phenomena only (screening by free carriers). Therefore polarization in metals is *not* a bulk phenomenon. The opposite is true for insulators: macroscopic polarization is a nontrivial, material-dependent, bulk phenomenon.

On the theoretical side, the concept itself of macroscopic polarization in quantum physics has long evaded even a correct definition: most textbooks contain incorrect statements [1]. The modern theory of polarization [2,6], based on a Berry phase [7], was developed a decade ago: it revolutionizes both the very definition of the relevant bulk observable, and the ways to compute it in real solids. This theory has been the subject of a previous article in this journal [8], and starts making its way in elementary textbooks [9]. The recent advances about the insulating state of matter [3,4] are deeply rooted in the modern theory of polarization: in fact polarization and localization can be regarded as two aspects of the same phenomenon, and stem from the same formalism.

In order to provide an oversimplified treatment, here I only deal with a system of N one-dimensional electrons, chosen spinless (or parallel-spin) for the sake of simplicity. The many-body ground wavefunction is then $\Psi(x_1,x_2,\dots x_j,\dots x_N)$, and all the electrons are confined to a segment of length L. Eventually, we will be interested in the thermodynamic limit, defined as the limit $N\to\infty$ and $L\to\infty$, while the density N/L is kept constant. For practical purposes, this limit is well approximated when L is much larger than a typical atomic dimension. A crucial role in our treatment is played by the boundary conditions chosen for the wavefunction: we adopt here-as almost mandatory in condensed matter physics [1]—Born-von Kàrmàn periodic boundary conditions, which amount to imposing that the wavefunction Ψ is periodic, with period L, over each electronic variable x_j separately. Equivalently, one can imagine the electrons to be confined in a circular rail of length L: the coordinates x_j are then proportional to the angles $2\pi x_j/L$, defined modulo 2π.

Following Refs. [2,3], the key quantity needed to deal with both polarization and localization is the ground-state expectation value

$$z_N = \langle\Psi|U|\Psi\rangle = \int_0^L dx_1 \dots \int_0^L dx_N |\Psi(x_1,\dots x_N)|^2 U(x_1,\dots x_N), \quad (1)$$

where the unitary operator U, called the "many-body phase operator" or "twist operator", is defined as

$$U(x_1,\dots x_N) = \exp\left(i\frac{2\pi}{L}\sum_{j=1}^{N} x_j\right), \quad (2)$$

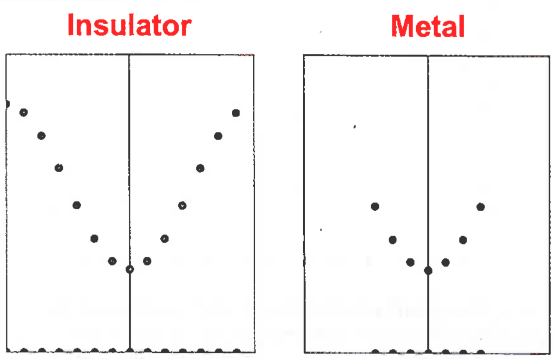
and clearly obeys periodic boundary conditions. The expectation value z_N is a dimensionless complex number, whose modulus is no larger than one.

The electronic contribution to the macroscopic polarization of the system can be expressed in the very compact form [2,4]:

$$P_{\rm el} = \frac{e}{2\pi}\lim_{N\to\infty} \mathrm{Im}\log z_N, \quad (3)$$

where e is the electron charge. Notice that, for a one-dimensional system, the polarization has the dimensions of a charge (dipole per unit length). The essential ingredient in Eq. (3) is Im logz_N, i.e. the *phase* of the complex number z_N. This phase, which is a rather peculiar kind of Berry phase [7], is ill defined whenever z_N vanishes. And here comes the key message [3,4]: what differentiates very sharply metals from insulators is the behaviour of the modulus of z_N in the thermodynamic limit: in the former materials it goes to zero, while in the latter it goes to one. We find therefore, in agreement with the above phenomenological considerations, that macroscopic polarization is well defined in insulators and ill defined in metals.

The modulus of z_N can be used to measure the localization of the many-body wavefunction, thus providing a quantitative



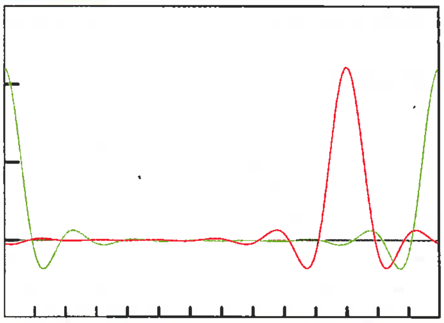
▲ Fig. 3: Same energy band structure as in Fig. 2, for a *finite* one-dimensional system with periodic boundary conditions. In drawing the figure, the period L has been taken as 14 times the lattice constant. In the insulating case the band is filled, and the ground wavefunction Ψ is the antisymmetrized product (Slater determinant) of 14 Bloch orbitals, whose k-vectors and corresponding energies are indicated by dots. Notice that only one of the states at the Brillouin-zone boundaries must be occupied to avoid double counting. In the metallic case the band is half-filled, and the ground wavefunction is the antisymmetrized product of the 7 Bloch orbitals whose energy is below the Fermi level, indicated by dots.

assessment of Kohn's [5] main idea. To this aim, we have introduced [3] the intensive quantity

$$\langle x^2\rangle_c = -\lim_{N\to\infty}\frac{1}{N}\left(\frac{L}{2\pi}\right)^2 \log|z_N|^2, \tag{4}$$

having the dimensions of a squared length. It can be proved [4] that, in insulators, the modulus of z_N differs from one by the order of $1/N$, hence $\langle x^2\rangle_c$ is finite, while in metals it is divergent: this finding clearly vindicates the classical viewpoint of Fig. 1.

I stress that $\langle x^2\rangle_c$ is an intensive property characterizing the localization of the many-body wavefunction Ψ as a whole, which applies on the same grounds to ordered/disordered and correlated/uncorrelated many-electron systems. It is now expedient to focus on a special case: ordered and uncorrelated, i.e. a crystalline system of independent electrons, as in the band-structure picture of Fig. 2, where a single band is considered. In this case the ground many-body wavefunction $\Psi(x_1,x_2,\dots x_N)$ is a Slater determinant (i.e. antisymmetrized product) of N single-particle orbitals, which are usually chosen in the Bloch form both for metals and insulators. But there is an outstanding difference, illustrated in Fig. 3: only one half of the band is used to build the Slater determinant for the metal, while the whole band is used for the insulator. These two Slater determinants are therefore qualitatively very different, despite the fact that both are built of (delocalized) Bloch orbitals. Their difference is probed very sharply by the many-body phase operator U, Eq. (2): in fact it can be proved [3, 4] that in the metallic case the expectation value z_N, Eq. (1), vanishes, thus leading to a formally infinite value of $\langle x^2\rangle_c$, while in the insulating case $\langle x^2\rangle_c$ assumes a finite value. Actual values of $\langle x^2\rangle_c$ in nonmetallic materials, as computed e.g. for the III-V semiconductors, are of the order of a few bohr^2. I stress that, in the present analysis, no use is made of the *spectrum* of the system: the metallic/insulating behaviours reflect a different organization of the electrons in the *ground state*.



▶ **Fig. 4:** The ground wavefunction Ψ of an insulator can be equivalently written as an antisymmetrized product of either Bloch orbitals (Fig. 3, left panel) or Wannier orbitals. Both Bloch and Wannier orbitals obey periodic boundary conditions over the period L, which we have taken as 14 times the lattice constant (same as in Fig. 3). For the sake of clarity, we have plotted (red and green) only 2 of the 14 Wannier orbitals which are needed to build Ψ. In the thermodynamic ($L\to\infty$) limit the Wannier orbitals are exponentially localized and the second cumulant moment of their distribution $\langle x^2\rangle - \langle x\rangle^2$ is finite: in fact it is equal to $\langle x^2\rangle_c$, Eq. (4). The situation is completely different in the metallic case (Fig. 3, right panel): one *cannot* write Ψ as an antisymmetrized product of orbitals whose second moment is finite in the thermodynamic limit. Notice that such a sharp qualitative difference reflects a different organization of the electrons *in the ground state*, and makes no reference to either the excitation spectrum or conductivity properties.

The intensive quantity $\langle x^2\rangle_c$, measuring electron localization in the many-body wavefunction, has the meaning of a second cumulant moment. Once more, it is expedient to illustrate this for the special case of a crystalline system of independent electrons, as in Figs. 2 and 3. Since a determinant is invariant under unitary transformations, we can perform any unitary transformation on the N single-particle occupied orbitals without affecting the ground N-particle wavefunction Ψ, and therefore leaving z_N and $\langle x^2\rangle_c$ invariant. Starting from orbitals of the Bloch form, hence delocalized throughout the crystal, we may look for a unitary transformation leading to orbitals which are localized around some crystalline sites. One such transformation, namely, the Wannier transformation, is well known in solid-state physics: this is illustrated in Fig. 4. According to our theory, $\langle x^2\rangle_c$ is the minimum possible value for the averaged second cumulant moment $\langle x^2\rangle$ - $\langle x^2\rangle$ of the electron distribution of the localized orbitals, in the $N\to\infty$ limit. One outstanding implication is that, for insulators, the many-body wavefunction *can* be written as a Slater determinant of localized single-particle orbitals, whose distributions have *finite* second moments. More precisely, the averaged second moment of the single-particle orbitals can be made as small as $\langle x^2\rangle_c$ with a suitable choice of the unitary transformation. Suppose, instead, that we attempt a localizing transformation on the occupied Bloch orbitals of a metal. Then, since $\langle x^2\rangle_c$ diverges, it is impossible that all of the transformed orbitals have a finite second moment in the thermodynamic limit.

In conclusion, the present theory of the insulating state sharply discriminates between an insulator and a metal *without* actually looking either at the excitation spectrum or at conductivity properties. Instead, it is enough to probe-with an elegant tool, the many-body phase operator of Eq. (2)-the organization of the electrons *in the ground state*. Once our simple definition of localization is adopted, electrons are localized in any insulator and delocalized in any metal. Localization in the ground electronic wavefunction is the key reason why insulators sustain bulk dielectric polarization. In the present treatment, localization and polarization appear as two aspects of the same phenomenon, and are naturally described by the same formalism.

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About the author

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STM as an operative tool: physics and chemistry with single atoms and molecules

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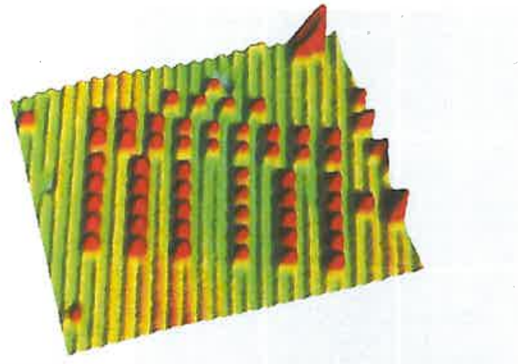
The scanning tunneling microscope, initially invented to image surfaces down to atomic scale, has been further developed in the last few years to an operative tool, with which atoms and molecules can be manipulated at low substrate temperatures at will in different manners to create and investigate artificial structures. These possibilities give rise to startling new opportunities for physical and chemical experiments on the single atom and single molecule level. Here we provide a short overview on recent results obtained with the new techniques.

Lateral manipulation and build-up of artificial structures

Fig. 1 shows a first example of an artificial structure on atomic scale. The Brandenburg gate has been formed with 48 CO molecules by laterally manipulating them into the proper positions with atomic accuracy [1].

In lateral manipulation an adparticle at the surface is moved with the tip along the substrate surface to the desired place without loosing contact to the substrate. This is achieved by bringing the tip very close to the adparticle, so that besides the ever present van der Waals interactions also chemical forces between tip and particle are coming into play. These forces can be tuned to be large enough to surmount the surface diffusion barriers,so that the adparticle comes along with the tip, if the tip is moved parallel to the surface to the desired end point. It is fascinating that even at the level of the very atoms, a distinction can be made between different manipulation modes, namely pulling, pushing and sliding [2]. Fig. 2 shows tip height curves obtained in the STM constant current mode during manipulation of metal atoms and CO-molecules. Fig. 2a displays the pulling behaviour of a metal adatom: The atom follows the tip in regular jumps from one adsorption site to the next due to attractive tip-particle forces. Applying larger forces (measured by smaller tunneling resistivities) a sliding motion is induced (Fig. 2b), in which the adparticle is trapped under the tip and follows the tip motion continuously, so that the tip height curve yields a picture of the substrate corrugation. In contrast to metal adatoms, CO molecules are usually pushed (Fig. 2c): The molecules move discontinuously in front of the tip due to repulsive forces. On close packed surfaces-like Cu(111), pushing is not very reliable, as the particles tend to move to the side of the tip and get lost. That the buildup of artificial structures like that in Fig. 1 is successful at all is due to the

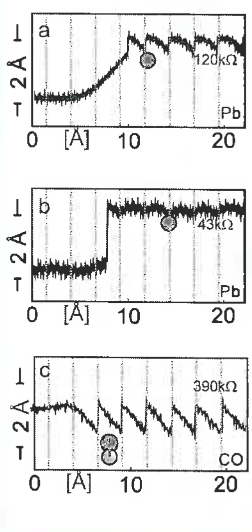


▲ **Fig. 1:** STM-image of the Brandenburg Gate constructed on Cu(211) with atomic precision using 48 CO-molecules using the technique of lateral manipulation.

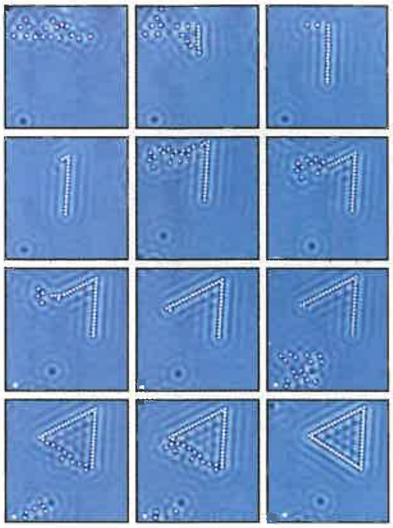
proper choice of the substrate surface: On Cu(211) CO adsorbs at the upper part of the intrinsic step edges, which act as "railway trails" upon pushing. The artificially created regular triangle whose buildup is shown in Fig. 3 has been made by pulling Ag atoms on a Ag(111) surface. With sufficiently stable and nevertheless sharp tips it is even possible to remove native substrate atoms from highly coordinated defect step sites and even from regular step sites of high index surfaces in a one by one manner [2]. This ability was used in analytic chemistry on the atomic scale by investigating the monolayer structure formed on Cu(211) upon Pb-evaporation at room temperature: Atom by atom removement from an island edge revealed that a surface Cu-Pb lead alloy had formed although the two metals do not mix in the bulk.

Vertical manipulation

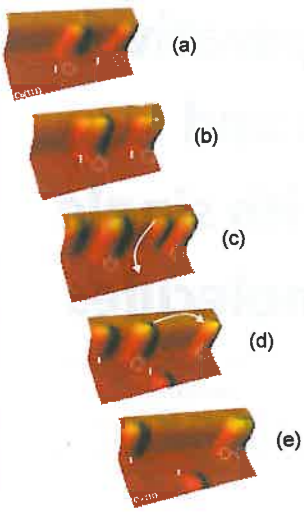
A different kind of manipulation concerns the deliberate vertical transfer of a particle from the surface to the tip and vice versa. Fig. 4 shows the principle together with an example [3]. Again the tip is brought close to the particle to be transferred until the force between tip and particle is sufficiently strong, so that the particle can go with the tip upon its withdrawal. Here electron current effects can help to transfer the particle in the wanted direction: The polarity should be chosen such, that the electrons flow in the transfer direction.



◄ **Fig. 2:** Tip-height curves measured during manipulation of (a) and (b) a Pb-atom and (c) a CO-molecule along step edges on Cu(211).The tip is moved from left to right and respective tunneling resistances are indicated as qualitative measures of the tip-adparticle force. The vertical dotted lines correspond to fcc sites next to the intrisic step edges. The initial sites of the manipulated particles are indicated. Note that in the attractive manipulation modes (a: pulling and b: sliding) the particles first hop towards the tip and then follow it, whereas in the repulsive mode (c: pushing) the CO-molecules perform hops away from the tip.



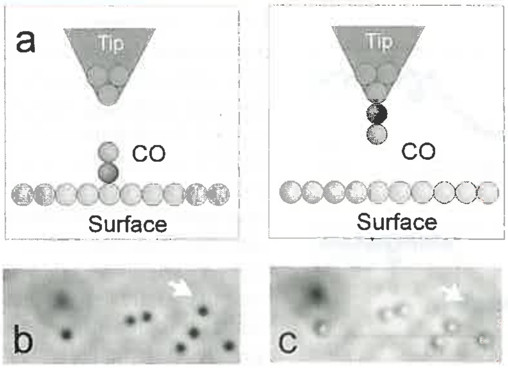
◀ **Fig. 3:** Series of images demonstrating the build-up of a regular triangle consisting of 51 Ag atoms on a Ag(111) surface.



◀ **Fig. 5:** Sequence of steps in STM-tip induced single molecule Ullmann reaction on Cu(111). All reaction steps including dissociation of parent iodobenzene molecules, motion of phenyl reactants and iodine byproducts as well as association of phenyl reactants to biphenyl have been induced with an iodine functionalized tip.

The STM pictures in Fig. 4b refer to an image of Cu(111) with several CO molecules and one oxygen atom in the upper left corner. All species are imaged as depressions with a tip consisting of metal atoms. The CO molecule designated by an arrow is then picked up with the technique of vertical manipulation and the same area is imaged again. Noticeably all CO molecules have changed in appearance to protrusions whereas the oxygen atom remains imaged as a depression. It is obvious that deliberate functionalization of the tip with different molecules may lead to chemical contrast, a feature very much desired in STM.

The vertical transfer of CO is interesting due to the fact, that CO stands upright on metal surfaces with the carbon atom binding to the substrate. Upon transfer to the tip, the molecule consequently has to turn around. A reliable experimental procedure for transferring single CO molecules was found to require ramping of the tunneling voltage and simultaneous decrease of the tip-molecule distance. The transfer mechanism was investigated in great detail and yielded the following picture. Voltage ramping supplies the minimum tunneling bias of 2.4 eV required to populate the CO antibonding 2pi* level. As the CO hopping rate depends linearly on the tunneling current, a one electron process is responsible for the excitation. Although only 0.5% of the tunneling current pass through the 2pi* orbital and the lifetime of the electrons in this antibonding level is only of the order of femtoseconds, the continuous supply of tunneling electrons eventually causes release of the CO from the surface. The approach of the tip in the pickup procedure just increases the probability that the molecule is "caught" at or near the tip apex upon desorption [3].



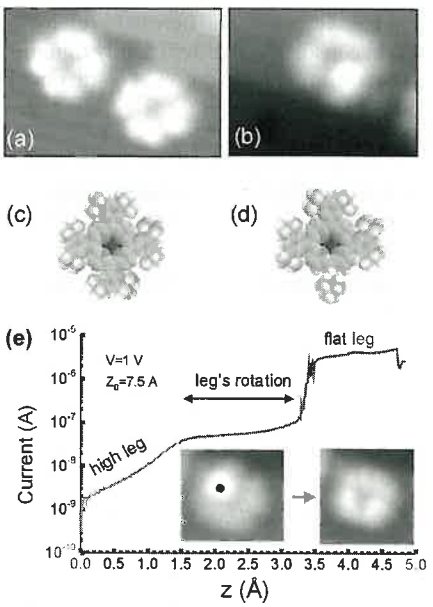
▲ **Fig. 4:** (a) Schematic picture of the flipping of a CO molecule upon vertical manipulation from the surface to the tip apex. (b) and (c) Demonstration of imaging changes obtained for CO-molecules with a CO-tip; notice that the image of the oxygen atom is unaffected. The white arrow denotes the CO-molecule which was transferred deliberately to the tip.

Chemistry with the STM-tip: Inducing all steps of a chemical reaction

Population of an antibonding state is also important in the preparation of reactants in a full chemical reaction induced by the tip [4]. In the so called Ullmann reaction, iodine has to be split off from the iodobenzene parent molecules to form the phenyl reactands. Again tunneling electrons populate temporarily the iodine-phenyl antibonding level thus causing the dissociation step (Fig. 5a, b). Both iodine and phenyl fragments are found on the surface. To induce the diffusion step to bring two phenyls together lateral manipulation in the pulling mode is employed (Fig. 5c). At the low temperatures of the Cu(111) substrate the proximity of the two phenyls is not sufficient to induce the association to biphenyl: If a pulling procedure is applied to the phenyl couple from one end, the phenyl on the rear does not go along. Only after injection of electrons the synthesis step is performed, which can be proven by pulling the product from one end and realizing that the entire molecule follows the tip (Fig. 5d). Notice that in Fig. 5c one of the iodine atoms was transferred deliberately to the tip after dissociation of the iodobezene and all the following steps were performed with the iodine functionalized tip. The iodine was finally put back on the surface (Fig. 5f). The synthesis of the two phenyls to biphenyl is probably connected with local excitation of vibrational modes in the phenyl groups enabling the two open bonds to find the proper relative orientation for bond formation. Local excitation of the scissoring and the OH-stretching modes was indeed observed to be responsible in tip-induced diffusion of water molecules adsorbed on Cu(111). Furthermore, hydrogen bonds can be formed and broken and thus ice clusters can be crystallized via the same mechanism.

A possible molecular switch realized by STM-manipulation

Manipulation can also be performed into parts of molecules as shown in Fig. 6 The chemical structure of a TBPP molecule is

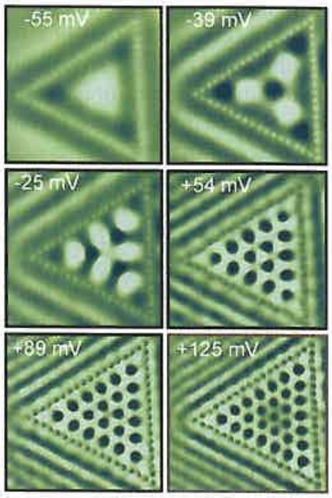


▲ Fig. 6: (a) STM image of a Cu-TBPP molecule on Cu(211) with its legs lying flat on the surface. (b) Image of the same molecule after one of ist legs has been moved up to a conformation almost perpendicular to the substrate by manipulation with the tip. (c) and (d) show models of the two conformations in (a) and (b). The observation that at the same tip height the current through the leg is different by orders of magnitudes in the two conformations can be used to realize the principle of a molecular switch. (e) shows the measured change in tunneling current upon pushing the leg with the tip from the vertical to the parallel conformation.

shown in Fig. 6a. To the center porphyrin ring there are four legs attached which are perpendicular to the center ring in the gas phase. On Cu(211), however the legs lie flat (Fig. 6b). Using lateral manipulation, a single leg can be transformed into an almost perpendicular conformation and the leg can be pushed back into the flat position with the tip again. As the perpendicular and parallel conformations exhibit orders of magnitude different conductivities these experiments point to the possibility of a molecular switch, in which a mechanical action causes switching from conducting to nonconducting behaviour [5].

Physics with artificial structures: Measuring electron lifetimes inside a quantum corral

Adparticles arranged in a closed geometry act as partial confinement for electrons and can be used to determine the electron lifetime [6]. By means of lateral manipulation 51 Ag atoms have been precisely positioned at distances of 5 times the nearest neighbour distance to form a triangle with a base length of 245 Å as shown in Fig. 3. The electrons of the surface state present on the Ag(111) surface are scattered by these Ag adatoms, resulting in a complex interference pattern. Energy resolved data as shown in Fig. 7 were taken in the spectroscopic dI/dV-mode. The energies in Fig. 7 correspond to energies where the wavelength of the electrons is in resonance with the triangle resulting in a strong enhancement of the intensity. Calculations of the wave pattern have been performed based on a multiple scattering approach taking into account the phase-relaxation lengths of the electrons, which reflect scattering events inside the triangle influencing their phase coherence and can directly be converted into electron life-

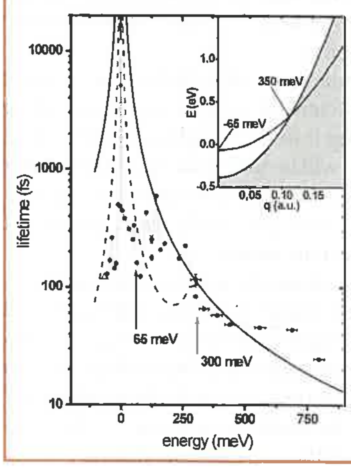


◀ Fig. 7: Spectroscopic dI/dV maps measured with the triangle of Fig. 3 displaying the local density of states at energies where the wavelength of the electrons are in resonance with the triangular quantum corral.

times. Inside of the triangle electron-electron and electron-phonon scattering determine the electron lifetime and the spatial decay of the interference pattern which has been measured here. Fig. 8 depicts the result of the evaluations for the electron lifetimes as function of energy. The measurements clearly show a sharp maximum at the Fermi energy in accordance with Fermi liquid theory for a 2DEG due to a decreased phase-space for electron-electron and electron-phonon scattering. Furthermore two pronounced edge-like features show up in the data at +65 meV and +300 meV as indicated in Fig. 8. The latter can be attributed to the transition of the surface state into a surface resonance. The former can be interpreted by a change of the scattering probability as the electron energy becomes smaller than the surface state binding energy of 65 meV. Finally, additional finestructure can be observed which has to be attributed to the geometrical influence of the triangle.

Outlook

The results described above relate to many diverse aspects of physics and chemistry on the atomic and nano-scales. Measuring tip-height curves in constant current or current curves in constant height mode during lateral manipulation reveals internal motion of the entities and thus refers to nanomechanics. The fact that small structures can be assembled or taken apart yields important routes to synthetic and analytic chemistry on the atomic scale. The possibility to take atoms out of the substrate



◀ Fig. 8: The full circles connected by straight lines denote the measured electron lifetimes in the triangle of Figs. 3 and 7. The open triangle is a measured value on a defect free terrace and the solid line represents an extrapolation of measurements above 1 eV. The dashed line is an adaptation to theoretical calculations for Cu(111).

from defect or intrinsic surface steps can be used to structure the surface itself with the possibility to include also layers deeper than the topmost one. The use of artificially created adatom-hole pairs as binary units with writing, reading and rewriting possibilities certainly would give rise to the utmost possible storage density. Artificial structures on the surface can be built either with native substrate atoms or adsorbed species and their properties can be investigated with spectroscopic methods. Important progress for nanoelectronics can be expected from the ability to modify with the tip internal molecule conformations. The successful induction of all steps of a complex chemical reaction using force, current and field effects raises the hope that new molecules can be built by taking different parent molecules apart and welding dissociation products together at will to synthesize new molecules, whose properties can be investigated again by tunneling spectroscopy. As controlled atomic manipulation allows the design of arbitrary scattering geometries, on the basis of a deeper understanding of the electron lifetimes it should become possible to even engineer these lifetimes, which are a key quantity in quantum computing and quantum transportation. A further important present goal is to transfer all possibilities outlined here to technologically important substrates like insulators; for sufficiently thin insulator films on metallic substrates the use of the STM is still possible.

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The impact of physics on society and the mission of physics education in secondary schools

Etienne De Wolf *

The impact of physics on society

Science is culture

In the last decades, scientific knowledge and technology have grown at a spectacular rate, and had a dramatic impact on society. Our society in Western Europe now even has become very dependent on technology: for its housing, heating, lighting, clothing, food, mobility, health care, safety and security. Without technology, most of our durable goods, public utilities, consumables and services would simply not exist. And physics is one of the most important sciences that are responsible for these developments.

But the impact of science would not have been possible without the contribution of other factors, which finally determine whether or not a scientific discovery will have an influence on society at all, and if it does, what kind of influence this will be. There is a long and complex way to go between a new scientific discovery and its effects on society.

Most citizens will only become aware of such discovery when it concerns a spectacular new scientific insight and if, on top of that, the media decide to bring it to the people's attention. And then in most cases they rightly will be told at the same time that it may take many years before we can expect any practical application of this discovery. But it is precisely these practical applications that have an impact on society.

If, for some reason, a scientific discovery is not used for new technology, then only a very limited group of citizens will be affected by it. Namely just those who cared to inform themselves, and who were lucky to have had a scientific education that enables them to understand what exactly this new discovery is all about. These few privileged people will probably be charmed once more by the beauty of nature or by the elegance of the new scientific theory.

So, even if there are no practical applications, scientific discovery still is a cultural enrichment for society. Therefore science is one aspect of culture. And it would be worth while to make this aspect of culture accessible to more people. That is possible, if we are prepared to invest in "professional vulgarization". Vulgarization is, in the first place, a task for scientists themselves, who should not consider this to be incompatible with their dignity. However, it also belongs to the mission of schools, cultural organizations and the media. Fortunately, every once in a while we see beautiful examples of serious vulgarization. But with all the spare time we now have available, and with all didactical means we now have at our disposal, there is certainly room for more. Good vulgarization of science has a positive impact on society.

Nevertheless, scientific discoveries only have a substantial impact on society if they ultimately lead to attractive new or improved products, with which we will deal in our day to day lives. And for this conversion of science into products, we need technology.

Science and technology

Science has to do with *knowing*, technology has to do with *acting*. Science comprises everything mankind knows about matter, energy, natural forces and laws of nature, and about the natural phenomena as they present themselves in the universe.

A scientist builds his knowledge on attentive observation, measurement, systematic analysis and carefully designed experiments. Starting from his own observations and those of his colleagues worldwide, a scientist constructs models and mathematical formulas, which bundle these observations into a coherent theory. His work is an effort to discover, identify and formulate the laws of nature. These laws describe the structure of matter, and the relationships between cause and effect. Science enables us to understand what is going on in nature, and to predict what is going to happen under what circumstances. The validity of such predictions is then tested in new experiments. And as soon as a theory is contradicted by one single new fact, it will be revised or refined. By systematically and consistently following this procedure, natural sciences have achieved spectacular new insights in how nature works.

Technology is something completely different. In science, we *discover* things, in technology, we *make* things. Technology is a body of methods, procedures and tools, *invented* by man, starting from what science has *discovered* in nature.

The purpose of science is "to understand, to explain and to predict". The purpose of technology is "to change the world", to bend things and situations towards goals that match the interests of those who control technology, and who dispose of the means to make things happen.

Economic thinking as the driving force

As soon as somebody has identified an attractive application of a new scientific discovery, economic thinking comes into the picture. And this is the third step in the chain: science, technology and economy. Scientific knowledge is a necessary condition for technology, but is not sufficient. The driving force for technology stems from economic thinking.

The purpose of economic thinking is to create maximal practical utility or pleasure with minimal efforts and means. The creation of useful and pleasant things on one hand, and economical use of means on the other hand, are fundamentally two valuable goals. Nowadays economic thinking is common practice in society. It is a basic tool for all industrial and commercial companies, as well as for non-profit organizations and public authorities. But because of this way of thinking, companies, organizations and authorities will exclusively invest in the development and exploitation of those technologies, for which the perceived "advantages" are greater than the required "offers".

> The driving force for technology stems from economic thinking.

The offers consist of time and money to be spent on product development, on the development of manufacturing techniques, on investments, raw materials, labor and advertising. Advantages and offers will be weighed against each other, and in order to make them comparable, both will be expressed in financial terms. If, on the long term, revenues do not outweigh cost, then companies will not engage in the project.

Companies are "communities of shared interest", with 5 participants: customers, personnel, shareholders, suppliers and society. Each of these participants contributes to the business-process in his own specific manner. Each participant engages to do so because he understands that he can only attain his own targets by cooperating with the other participants. So, companies fulfil a social-economic role in society. Companies create products and services for their customers, income for their personnel and for their suppliers, and a financial compensation for the money their shareholders put at risk. Companies also pay taxes, which generate means for the financing of public utilities and services.

In order to fulfill this multiple function, companies must also make a profit. Contrary to what some people think, profit is not a "redundant surplus". Making a profit is not a crime. It is a duty! Corporate taxes as well as dividends for the shareholders can only be paid out of the pot of what legally is defined as "profit before taxes". Furthermore companies also have to keep part of their profit within the company, in order to safeguard their future existence. Indeed, retained profit must serve to finance growth, to finance adaptation to technological progress, and must serve as a buffer against bad times. Without profit, a company will not be able to fulfill its social role in the future. It will not be capable to continue to reward its shareholders, nor to deliver competitive products, nor to supply jobs. Profitability is a social obligation of a company, in the interest of all participants in this "community of interest", and thus in the interest of society.

Therefore companies will focus their means on activities that yield more than they cost. The principle of economic thinking substantially determines which applications of science will be technologically exploited and become visible in society. Economic thinking is the driving force for the impact of science on society.

Market-economy

In a market-economy, the "economic value" of a new product, as well as its cost, are both determined by the mechanism of supply and demand. These two factors determine what quantities will be sold and bought, and at what price.

Supply and demand both result from the interaction between technical possibilities on one hand, and a combined play of sociological and demographic factors on the other side. Supply and demand depends on what citizens perceive as attractive. And this in turn depends on their social status, their education, their age and their moral values. It also depends on the alternatives from which they can choose, on what their idols do and wear, and on what people see and hear in advertising. The structure of the market, the perceived attractiveness of products to potential buyers, and the outlook on profitability for manufacturers, are the factors that will determine which applications of science will effectively have an impact on society.

Competition sets the standards

Another important factor in market economy is competition. Competition continuously raises the standards for technological realizations. Competition forces companies towards ever better performance. The best performing company automatically becomes the point of reference for all others. Consumers do compare and choose without compassion. If other suppliers do not succeed to match or exceed the performance of the smartest competitor, these companies will not survive. Consequently, standards of "quality for money" will be raised step by step. Thanks to competition society gets more value out of scientific discoveries. And that of course is good. We now can buy a pocket-radio that is a hundred times smaller than a radio 50 years ago, which produces a much better sound and has more functionality, at a price that is only a fraction of what it was before.

Absence of competition stops technological research. Just look at what happened in Eastern Europe before 1989. They had a "guided economy", where national authorities decided what should be developed, what and how much should be produced, by whom, and at what price it had to be sold. We all know the result: people lining up for small, but scarce and expensive, toy-like cars, called "Trabants". And that was not caused by Russian ignorance of scientific discoveries. Russian physics was not different from Western physics! Their poor realizations were due to lack of competition, and that caused the collapse of their system.

The co-ordinated actions of science, technology and market-economy have not only created better products at lower prices, they also have enabled us to drastically decrease our working time. In Belgium we only work 1.500 hours a year. And we hardly have to do this 40 years long. Whereas our life-expectation now exceeds 70 years. A simple calculation proves that now about 90 % of our (prolonged) lifetime is available for education, for recreation, for sports, for personal care, for communicating with others, for making other people happy, for enjoying culture, and for relaxing. To a great extent, this has been made possible thanks to technological, and economically profitable, applications of physics!

The flip-side of the coin

Nevertheless it would be unfair to conclude that everything that results from "profitable applications of physics", would be a blessing for society. Market economy, just like anything else, has its limitations and its drawbacks. But that is no reason to throw it away. It's only a good reason to add an extra factor to our chain.

In my opinion the three main limitations of market economy are:

1. that producing good things, based on science and technology, may have undesired negative side-effects, which are not automatically taken care of by market mechanisms
2. that science and technology can also be used to create "profitable rubbish", "profitable crime", or even "profitable warfare", and
3. that quite a number of good things in society, and even some of the very best, can not be generated by market mechanisms (and most of them don't even require science or technology either!)

Every coin has its flip-side! We can't make omelets without breaking eggs. We can't technologically manipulate nature without disturbing it. Technology implies extraction and consumption of raw materials. It consumes energy and produces waste. As long as the negative side-effects are minimal, we readily will accept them, and live with it. But on "space-ship earth", the home of society, we must survive with what we have aboard, and with anything that reaches us from outer space. This is an inevitable fact, with which we have to cope. If, in applying science, we exhaust irreplaceable resources, or produce more garbage than our space-ship can take, then we are putting society at risk.

the disadvantages of our technological actions should be taken into account

In fact, the disadvantages of our technological actions should be taken into account in our economic calculations. However, some of these escape from such calculations. Think of disadvantages that are suffered by third parties, which even don't enjoy any of the positive effects. Likely victims are the biosphere, weaker segments of society, or future generations. As long as these negative effects can not be charged as a cost to those who cause the disadvantages, they will not figure in the calculations.

Corrective measures

Negative side effects that can not be eliminated by market economics, can be mastered by "corrective measures". Doing this, adds an additional step to the chain that links science to society. Whether science will have an impact on society at all, and what this impact will be, now already depends on four factors: scientific discovery, technology, economic thinking and corrective measures.

As far as corrective measures is concerned, a series of considerations have to be made:

1. Corrective measures can be self-imposed by an individual company or a group of companies, as a sign of "responsible citizenship". But in most cases they are imposed by a central authority, or in a democratic way, as is the case in Western Europe. There is however a problem with democratic decision making for such complex matters as technologic or scientific progress. It is indeed quite unlikely that all participating citizens and their representatives are technically capable to make a fair balance between the pro's and con's, and to judge which of the proposed rules are wise and which are not.
2. All corrective measures have their price. Rules, by definition, limit our freedom. So, if society wants to prevent certain negative effects, it will have to renounce the attractive side of what is being forbidden. We must have the courage to choose.
3. As globalization is penetrating society, we cannot afford to maintain stringent measures here, when other parts of the world compete with us without caring about the negative effects. Therefore globalization of business requires a corresponding, adequate globalization of social and ecological correcting measures. In this area I think a lot of work is still to be done.
4. Some negative effects will escape from all *measures*, as they concern drawbacks, which are unknown by mankind in the present state of our scientific knowledge. The most striking consideration in this respect is that, in a way, everything depends on everything, that we are citizens of the universe, and that this cosmos is far too complex to ever be completely understood by man. This means that we can not oversee all the consequences of our acts. And that should motivate us to practice a certain degree of modesty. Science is not omniscient. Therefore in case of doubt we should refrain from action. In fact, this could be proclaimed to be a "rule of the game" too. Wouldn't that be wise?
5. Not everything that is technologically possible and economically profitable is automatically compatible with our ethical standards. Ethics does not result from scientific research, or from technology, or from economic thinking, or from democratic decision-making. Some possible applications of science are bluntly crimes. But others are considered to be acceptable practice by some people, but are unacceptable to others. And this calls for another step in the chain. I'll come back on this below.
6. The only way to achieve a situation where society can fully enjoy the positive effects of technological progress, without having to accept all the negative side-effects, is to continue scientific research, so that we can develop new, improved technologies, which eliminate the major drawbacks.

Individual responsibility

Scientific discovery, technology, economic thinking and corrective measures are four elements, which, together, determine the impact of science on society.

But there is still another factor that deserves more attention and which, in my opinion, may well become the most important one. Apart from natural phenomena, all changes in society result from actions of man. People are the ultimate driving force behind all factors that have an impact on society. Science obviously is the basis for all technology. Market-economy clearly constitutes the most efficient way to produce welfare at minimum cost. Democratic decision-making appears to be the safest way to reduce undesirable negative effects, and to safeguard our social and ecological values.

However, "what the market demands and offers", or "what the political majority decides" is always the result of decisions of many individuals. In this complex process every citizen must be aware of his or her co-responsibility. As an individual citizen you are not left without power, at least if you join forces with others.

But even if your position is not shared by anyone else, then, as an individual, you still have quite some latitude to do what you really want to do. It is not because it is trendy to buy a product, that we *have to* buy it. It is not because democratically voted rules do not forbid certain actions, that we are *obliged* to commit them. Ultimately you can, within certain limits, decide and live according to your own principles. As long as you don't violate the very few basic principles of human dignity. In most cases there is really no excuse to hide behind rules, if these are in conflict with our conscience.

And that completes the chain of factors that link science to society. Scientific discovery, technological applications, economic thinking, corrective measures and individual responsibility are the 5 cornerstones of any progress in society.

This brings me to my second theme:

The mission of physics education in secondary schools

Do you really need physics?

Allow me to be nasty for a while, and to boldly ask the question whether we need physics education in secondary schools at all? Do you really need physics to become a good factory worker? Or a good bookkeeper, or an efficient salesperson, or a good bus-driver? Do you need to understand the laws of Ohm and Kirchoff in order to be able to push the button to switch on the light? Will you be a better communicator in using your GSM when you understand the laws of electromagnetism? Will you do better cooking if you know how microwaves work? Do people feel they are better citizens or better parents because they had lectures in physics in secondary school? My guess is that very few citizens would answer these questions by a definite "yes". A minority would probably answer that "it was not really necessary, but that nevertheless it was nice". Whereas the majority would bluntly say "no" without any scruples!

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Of course if you want to become a technician, specialized in electricity, and if secondary school is the final level of your formal education, then you will want physics classes that inform you on electricity. Indeed, as an electro-technician you must be able to solve practical problems in an electrical circuit or machine. And then it is useful to understand what you are doing. In this case physics teaching in secondary school is an element of your professional training, and your employer will most certainly want to see your diploma. Although it is very likely that he will give you some dedicated training for repairing his specific products. You will probably even receive a handy manual, containing all the steps you blindly have to go through in order to detect the defect and to solve it by simply replacing the defect component, not by repairing it! So even in this case you could ultimately argue that secondary school should better replace physics teaching by a training in correct reading and using manuals!

Maybe I'm exaggerating. Let's say that we all agree that the future electro-technician does need physics teaching in secondary school. But wouldn't it be sufficient to have physics in technically oriented school-programs, and only in those? Is there any good reason to insist on physics teaching in the other orientations of secondary schools?

Education

The answer of course is clear: schools must provide for education, but education is more than just the transfer of know-how and skills that are focused on immediate practical utility.

The purpose of education is "to prepare young people to become responsible citizens".

In order to deserve the qualification "responsible", a citizen must be able

1. to cope with the world
2. to develop his personality
3. to contribute to the future and
4. to balance conflicting factors

So these are, in my opinion, 4 elements on which education must focus.

Let's take a closer look at each of them.

"Coping with the world" means

- that you know what the physical world and society have to offer
- that you know what is attainable and what not
- that you are familiar with the rules of the game of the cultural sphere in which you are raised
- that you are "willing and able" to conform to these rules, at least to the minimal extent that is required to avoid serious conflicts
- that you have acquired certain skills and attitudes, which you need to function more or less "normally" in your family, among your friends, with your neighbors, in your job, in your country, in the European Union, and aboard our "space-ship earth"

It also implies

- that you are willing and able to adapt to change
- that you can communicate and cooperate with others
- that you can enjoy the beauty of nature, accepting the unpleasant aspects of it
- and that you can respect and enjoy the technical and organizational realizations of humanity over history, accepting that the coin also has a flip-side.

"Developing your personality" means

- that you learn to identify your individual capabilities and restrictions
- that you learn to enjoy your strengths and to live with your weaknesses
- that you see set-backs and failures as challenges to learn to do better
- that you are prepared to invest in "learning to do", in "learning to learn" and in "learning to think"
- that you learn to stand up for your self
- that you learn to respect other people and their ideas
- that you learn to take initiatives and to accept that initiatives unavoidably imply risks

- that you learn to enjoy helping other people
- that you can position yourself in society, and see your role in each of the greater systems of which you are part, whether you like it or not,
- and finally that you can find *sense* in your life and in what you are doing.

"To contribute to the future" is a task for each citizen, irrespective of his position. Some of our present students will become our future political leaders, professors, business-managers or union-leaders. Others will hold responsible positions in administration or in social or cultural organizations. Or will become opinion-leaders, journalists, tastemakers, or militants in pressure groups. These people will be confronted with important new challenges and opportunities, about which they will have to take decisions that will affect the life of our children and grandchildren. I think their most important responsibility will be the creation of "a durable economy and a durable society". They also will have to make rules for "corrective actions" regarding

- the use of energy and raw materials
- the management of waste and
- the care for safety and security of technology and of society.

Being challenged by new facts, new insights or new discoveries, they will even have to fine-tune, renegotiate or revise some of our traditional values and priorities.

But not only people in leading positions will contribute to the creation of our future. Any citizen will, to a certain extent, influence the changes in society: either as a parent and educator, or as a consumer, as a worker, as a member of social or cultural organizations, as a private investor, or ultimately as a voter.

The fourth requirement for "responsible citizenship" is "balancing conflicting factors".

Education should help young people in learning to balance

- "interests on short term" against "interests on the long term"
- "innovation" against "conservation"
- "personal interest" against "common interest"
- "the interests of the community with which we identify ourselves" against those of "differentiated communities"
- "fighting to improve things that we believe we effectively can improve" against "accepting things that we feel we really can't change"

We must also help our students in learning to balance

- "tolerance" against "looking away" or "confrontation"
- "living in harmony" against "engaging in conflict"
- "appreciating differences as an enrichment" against "striving for unity"
- and to balance "the interest of man" against "the conservation of our biosphere".

Preparing children and adolescents for adult life is an enormous responsibility, to be shared by parents, schools and social organizations. In this process secondary schools are particularly important, as they deal with youngsters in the most critical phase of their development.

Physics education

Physics education is not an item on its own. In my opinion, physics education in secondary schools should be an integrated component of the "total educational project" of the school. As we have more than one network of schools in Belgium, as education is a matter that belongs to the competence of the regions, and as most schools offer several programs with different orientations, we should not be surprised that we find a variety of "total educational projects". And to me this variety is an asset. But whatever differences there are in accents, any total educational project must be oriented on the "general mission of education", as we have tried to describe it, namely "to help young people to become responsible citizens". Accordingly, any specific subject, whether it be physics or history, must contribute to that goal. I believe that in teaching physics, just like in teaching any other subject, there are many occasions to inject one or more of the many items that we listed under the 4 factors:

- coping with the world
- developing personality
- contributing to the future and
- balancing conflicting factors.

Just picking one item here and there, I think physics teaching can

- create occasions for the students to learn to communicate and cooperate with others
- invite them to respect and enjoy the scientific realizations of humanity over history
- give students a chance to identify their individual capabilities and restrictions
- challenge them to stand up for themselves and to respect other students and their ideas
- challenge them to take initiatives and to accept failures
- require that they take responsibility for their own future when they will finish school, or
- teach them to balance the interest of man against the conservation of our biosphere.

Furthermore, due to its specific subjects, physics teaching is in a unique position to make very specific contributions to *general education*. For instance

- by provoking astonishment, amazement and respect for the incredible beauty of matter and of the forces that reign in it
- by explaining the practical meaning of a number of physical notions with which we are confronted in our day to day life
- by familiarizing people with "neat thinking" and with the "scientific approach", including rigorous observation and experimentation, measuring the world, working with tentative assumptions, challenging assumptions and correcting them as required by new facts, and appreciating the limits of extrapolation. This methodical way of thinking and acting is not only applicable to physics, but also to a number of small or bigger private or professional projects, in which any citizen will sooner or later be engaged!

Physics teaching is also in a good position to indicate that history of science demonstrates that what we believed to be a reliable physical theory in the past, in many cases has proven to be inadequate, after we took an extra look, with better tools or under new circumstances. And physics teaching is a unique occasion to recognize that some modesty is required, as science understands only a small part of material reality, and that we can not oversee the ultimate consequences of all technical manipulations.

In conclusion, the mission of physics teaching in secondary schools is not only to convey practical skills and knowledge about the structure and behavior of matter, but also, and maybe in the first place, "to contribute to education for wisdom and responsibility".

Most certainly this can be very exciting for teachers. And for students as well.

* Edited version of the talk delivered at the "Physics Teaching Forum", organised on March 16th, 2002 in Brussels by the National Committee for Physics of the Belgian Royal Academy of Sciences,. The author is a physicist. He held several management- and board-positions at the world-wide Agfa-Gevaert Group and is Executive Professor at the University Antwerp Management School. He is a Belgian citizen and father of a happy family with 3 grown-up children. The author emphasises that this article is not based on any systematic research on the needs for physics teaching, but merely represents his personal view.

Let's talk about it

Aart W. Kleyn, Chairman, EPS Physics Education Division and Leiden University, The Netherlands

It is a very positive thing that Dr de Wolf, with his strong background in physics, business and management, expresses his views on physics education in secondary schools. More attention for physics at secondary schools is badly needed, and his initiative is very welcome. It demonstrates that physics education is appearing on more and more agendas. Dr de Wolf's systematic analysis clearly betrays his education as a physicist. I have a few thoughts on the analysis that I want to mention here. For instance, it is hard to maintain that scientific discoveries only have impact on society if they lead to products. Think about the impact that Galileo had on thinking and religion. Think about the impact of quantum mechanics on philosophy and the arts. I disagree that society is exclusively the market place. Government and its agencies have a very powerful role in society. Both employ many physicists and they are not always market oriented. It is an interesting notion that globalisation will require 'corrective measures'. I remark that physics essentially always has been global, and therefore it needs less corrective measures and can set an example for others. In the same context, Dr. de Wolf remarks that science is not omniscient. However, science will definitely come much closer to that if it is disconnected from the acts of certain factions in society, in order to try to foresee what the consequences of science (done by others) will be. In case of doubt, we should call for more science, and in many cases not refrain from action.

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More to the main topic of the article: in the discussion about physics education in high schools I miss the discussion about content in connection with the level of education. The physics that one needs depends on the type and level of the job. And education should differentiate. To implement this differentiation well is a major challenge, especially since the career path after a certain education can be so broad. The discussion on education seems to be concerned with low-level technical education. I hope Dr de Wolf does not want to turn everyone into a robot, well versed in correct reading of manuals. My former research technicians were not keen on continuing their careers into such kind of jobs, even though their formal training in physics was sometimes very limited.

I believe what has to be added to the discussion started by Dr de Wolf are questions such as: Do we attract good physics teachers with general statements, and how do we attract them? How do we introduce the concept of general laws, based upon observation and mathematical theory, rather than upon conviction, religion of political view? What is the role of experiment and careful, critical observation? How do we build equipment for such observations? How do we turn quantitative observation into a mathematical theory? What are the laws of physics that pupils need to know? What are the ingredients of physics that 'everybody' ought to know? Is it stimulating to bring new physics into the class-room? A lot of the content connected to the points mentioned above will certainly contribute to the general points made by Dr de Wolf, and they create useful skills and knowledge for the pupils.

Without such discussions on the explicit content and its implementation I am afraid that general statements such as "the purpose of education is to prepare young people to become responsible citizens" will only be used to eliminate physics from high schools. In my country this process is well under way. I thank Dr de Wolf for stimulating our thinking about physics education in general. Within the activities of the Physics Education Division we will keep his remarks in mind and hope they will stimulate further discussion on physics education, perhaps also on the pages of this Journal.

The author replies

An open discussion and confrontation of opinions, backed by experience and supported by arguments, are the most reliable basis for improving our knowledge.

Furthermore I agree with Prof. Kleyn that the impact of science on society is not restricted to "products". His reference to thinking, religion, philosophy and even to arts is very to the point. I consider this comment as a valuable complement and correction to my own statements. For which I'm grateful.

Initiatives by governments and agencies based on new scientific discoveries indeed also have an impact on society, but the results of such initiatives, although not directly financed or promoted by companies, in fact can be regarded as "products" as well.

However it seems unfair to suggest that I might "want to turn everybody into a robot, well versed in correct reading of manuals". Careful reading of my text reveals that I plead for the contrary. But we should face the fact that technicians in a number of cases are "reduced" to that role.

If statements such as "the purpose of education is to prepare young people to become responsible citizens" would drive authorities to eliminate physics from high school programs, then the conclusion should not be that the purpose of education must be something else, but rather that these authorities draw the wrong conclusions. This should stimulate us to increase our efforts to convince these authorities that physics teaching can contribute substantially to the education of young people to indeed become responsible citizens! Formulating arguments for this view is the essence of the second part of my article.

Spiral patterns in swirling flows

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Spiral galaxies, atmospheric or oceanic circulation, bathtub vortices, or even stirring tea in a cup, are examples that illustrate the ubiquity of swirling flows at all scales in nature. They are not only fascinating, but also of great importance in a number of industrial or practical applications.

Earth rotation provides the most spectacular illustrations of rotating flows. At the end of the XIXth century, during the earlier polar expeditions, the Norwegian oceanographer Nansen noticed that the iceberg drift was not along the wind direction, as expected, but rather towards the right [1]. The Swedish physicist Walfrid Ekman, who saw the influence of the Coriolis force in this problem, gave an explanation for this phenomenon in 1905. For an observer in the Earth frame, a linear motion will appear as curved, with a deviation to the right in the Northern Hemisphere. Likewise, the upper layers of water, over a depth of about one hundred meters, are dragged by the wind with a deviation towards the right [2]. The large oceanic motions originate from this phenomenon, and the same goes for the iceberg trajectories!

Let us consider a simple experiment, perhaps closer to our daily life. You have surely noticed that, when stirring tea, the tea leaves or other small solid particles heavier than water were collecting towards the centre of the bottom of the cup. Perhaps you would have expected the centrifugal force to expel them outwards! The friction at the bottom of the cup actually explains this seeming paradox. The centrifugal force, which varies as the square of the velocity, is weaker at the bottom, giving rise to a recirculation flow (see Figure 1). This inward recirculation is usually called the Bödewadt layer (1940), after the German fluid mechanician who described the motion of a rotating fluid over an infinite wall at rest.

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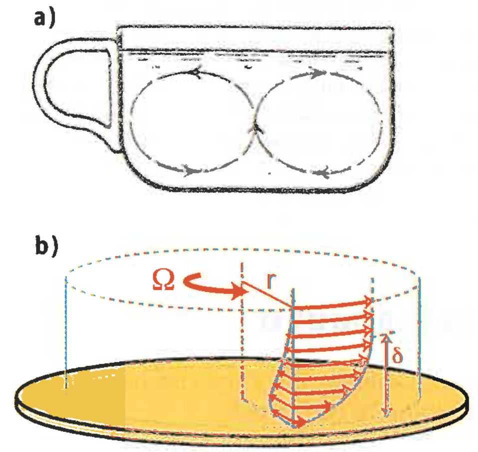
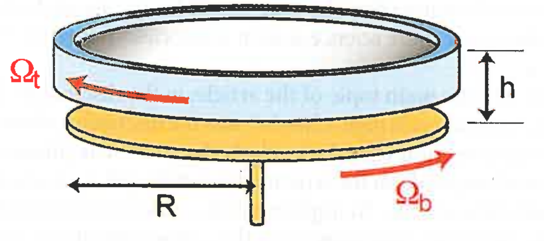
However, Albert Einstein was the first to give an explanation of this phenomenon in 1926 in the case of the teacup! [3] (It is said that, with this explanation, Einstein appeased Mrs. Schrödinger's curiosity, which her husband could not satisfy).

The region of fluid slowed down by the wall friction is called a *boundary layer*, and plays a key role in fluid mechanics. Its thickness, δ, is given by the lengthscale where the imposed rotation Ω is diffused by viscosity in the intermediate fluid layers. In the ideal case of a fluid rotating over an infinite wall, the balance between centrifugal and viscous forces yields $\delta \approx (\nu/\Omega)^{1/2}$ (where ν is the kinematic viscosity of the fluid), which is a constant, independent of the radius r. Such a situation is said to be *self-similar*, *i.e.* the velocity profile remains unchanged when distances are rescaled. According to each situation, Ω may be the fluid velocity, the wall velocity or the relative velocity between the two. Within this self-similar description, since δ is the only lengthscale of the problem, all the physical phenomena are expected to take place on a scale of order δ.



▲ **Fig. 1:** (a) Original Figure by Einstein (1926), from his paper about the formation of meanders in the courses of rivers [3]. The rotation of the fluid is slowed down close to the bottom of the teacup, on a boundary layer of thickness d. (b) The centrifugal force in this layer is then much lower than in the rest of the fluid, giving rise to a recirculation flow which brings together the tea leaves in the centre of the cup.

On the other hand, when the wall or the fluid extent is not infinite, other length scales, such as the teacup radius or the tea depth, may play a role too, and self-similar solutions are no longer of any help. Let us consider for simplicity the situation where the fluid is confined between two rotating disks—the upper one may be the free surface of the tea. In the general case, two boundary layers may be present, a centrifugal one over the faster disk and a centripetal one over the slower disk. Actually, the equations of motion without the self-similar hypothesis are so complex that no exact solution are known for this simple problem, even in the stationary regime. This problem gave rise to a famous controversy in the history of fluid mechanics: George Batchelor (1951) argued that two boundary layers, separated by a solid body rotation core, must take place in the fluid, whereas Keith Stewartson (1953)



▲ **Fig. 2:** Experimental set-up. The top disk is transparent, in order to allow visualisation from above. It rotates together with the cylindrical endwall (blue). The bottom disk (orange) is distant from the top disk by a few mm up to several cm. In this picture, the bottom disk has been lowered for visibility.

claimed that only one boundary layer should be present [4]. It has actually been shown, many years later, that a large variety of solutions may coexist in this flow, including the ones of Batchelor and Stewartson.

The stability of rotating flows is of considerable practical interest. Hard-disk drives are an important example: the instabilities of the thin air layer over the rapidly rotating platters induce vibrations of the read/write heads, that may damage the platters' surface [5]. The general problem of the stability of rotating flows is very complex, mainly because of two antagonistic effects: On the one hand, rotation tends to stabilise the flow, by inhibiting the perturbations about the rotation axis, eventually leading to a two-dimensional state. On the other hand, the confinement generates differential rotation (basically because of the wall friction), leading to centrifugal forces imbalance and possible instabilities. In this context, there is no hope to obtain exact solutions, and only experiments or numerical simulations are able to shed light on the physical mechanisms responsible for the instabilities in rotating flows.

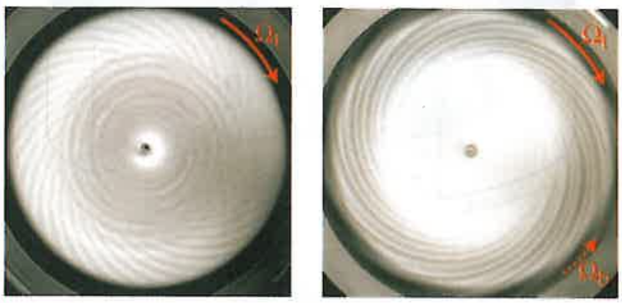
A rotating disks experiment

In order to study the instabilities of the flow between two rotating disks, the experimental set-up shown in Figure 2 has been built [6-8]. It consists of two coaxial disks, each of radius R=14 cm and separated by a distance h, which can be varied between a few mm up to several cm. The upper disk is the cover of a cylindrical rotating tank filled with a solution of water and glycerine, in which the lower disk can rotate independently. The upper disk is transparent, allowing us to visualise the flow from above. Small anisotropic flakes are seeding the working fluid, and their orientation with the velocity field leads to variations of the reflected light. For instance, the bright regions in the following pictures correspond to mainly horizontal flakes, whereas dark regions are associated with mainly vertical flakes.

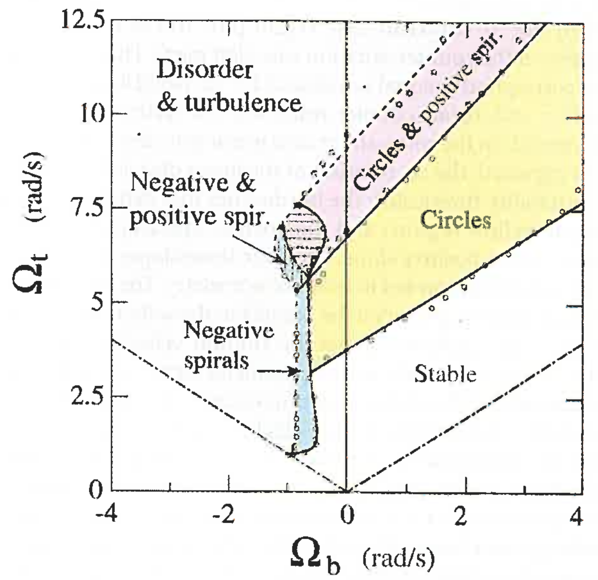
Each disk rotates with its own angular velocity, Ω_t and Ω_b. We call co-rotation the situation where both disks rotate in the same direction (Ω_t and Ω_b are of the same sign); the instabilities of this flow are first described. The much richer patterns arising in the counter-rotating flow, when the two disks rotate in opposite direction, are analysed in a second part.

Boundary layer instabilities

Let us first consider the flow when only one disk, the upper one, rotates: this is the rotor-stator configuration ($\Omega_t \neq 0$ and $\Omega_b = 0$). When slowly increasing the disk velocity from 0, nothing appears: the light reflected by the flakes remains homogeneous. The flow



▲ **Fig. 3:** (a) Circles and positive spirals in the rotor-stator regime. These patterns result from boundary layer instabilities. (b) Negative spirals in the counter-rotation regime. This pattern originates from a shear layer instability.



▲ **Fig. 4:** Regime diagram of the different instability patterns in the small gap case (h=7 mm). The right part (Ω_b>0) corresponds to the co-rotation case, and the left part (Ω_b<0) to the counter-rotation case [7].

may be seen as doubly symmetric: it is invariant with respect to any rotation (axisymmetric) as well as any time translation (stationary). Above a given disk velocity, a first instability pattern appears in the form of annular vortices, simply called *circles*, propagating towards the centre of the cell, as shown in Figure 3a. In this case, the temporal symmetry is broken, but the axisymmetry remains. If the angular velocity is further increased, another instability appears in the form of a spiral pattern. The axisymmetry of the flow is now broken too. This second pattern received the name of *positive spirals*, because they roll up to the centre in the direction of the rotating disk.

A careful inspection of the Figure 3a allows us to understand the nature of the instability that gives rise to these patterns. One can see the spiral arms do not extend over the whole flow, but rather stop at a well-defined radial location, where the boundary layers of each disk merge. In other words, for $r > r_0$, where the positive spirals can be seen, the boundary layers are separated, whereas for $r < r_0$ the viscous effects dominate the flow over the whole gap and no boundary layer can be defined. This observation suggests that positive spirals only exist within the boundary layers, and that they are the result of boundary layer instability. Additional observations, by means of visualisations in the vertical plane normal to the disks, confirm this assumption.

What happens now if the lower disk rotates too? From the frame rotating with the lower disk, this situation is similar to the one where only the upper disk rotates with a relative angular velocity $\Delta\Omega = \Omega_t - \Omega_b$. As a consequence, the instability threshold should just get shifted upwards, of a quantity Ω_b. Unfortunately, this picture is rather naive: the dynamics in a rotating frame is very different from that in the laboratory frame. In order to take into account the non-Galilean nature of the rotating frame, one should consider the effect of the Coriolis force on the instabilities.

We show in Figure 4 a diagram that summarizes our observations when both disks are rotating. The vertical and horizontal axes correspond to the angular velocities of the bottom and top disks. By convention, Ω_t is always positive, while Ω_b may be positive in the co-rotation case (right part of the diagram) or negative in the counter-rotation case (left part). The two dashed lines correspond to equal velocities: $\Omega_t = \Omega_b$ (solid body rotation) and $\Omega_t = -\Omega_b$ (exact counter-rotation). The vertical line, $\Omega_b = 0$, corresponds to the rotor-stator case previously described.

As expected, the co-rotation of the lower disk shifts upwards the instability thresholds: the borderlines that delimit the circle pattern (yellow region) and the positive spirals pattern (pink region) have a positive slope. However, these slopes are different, which can be interpreted in terms of symmetry. The borderline of the circle pattern appears to be parallel to the solid body rotation line, $\Omega_t = \Omega_b$, indicating that the angular velocity difference $\Delta\Omega = \Omega_t - \Omega_b$ is the only control parameter for this instability, and no influence of the global rotation occurs. In other words, the instability responsible for the circle pattern, which does not break the axisymmetry, is not affected by the additional rotation of the frame, *i.e.*, by the Coriolis force. By contrast, the borderline for the positive spirals, which are responsible for the axisymmetry breaking, has a larger slope than the solid body rotation line: in this case, the relative angular velocity $\Delta\Omega = \Omega_t - \Omega_b$ is not the only control parameter, and an extra velocity of the upper disk is needed for the positive spirals to arise. The global rotation has now the expected stabilising effect mentioned in the introduction.

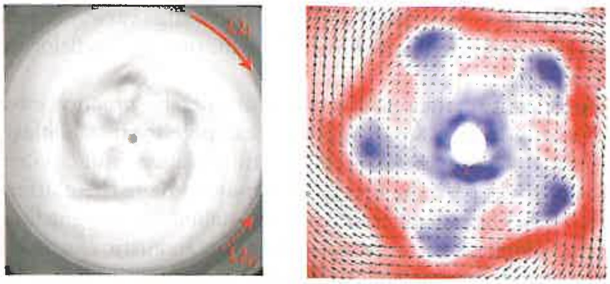
Shear flow instability

So far we have restricted our attention to the co-rotative ($\Omega_b > 0$) and weakly counter-rotating (about $\Omega_b > -0{,}5$ rad/s for this gap) regimes. The observed phenomena are rather different if we now focus on a more intense counter-rotating regime, where a new instability pattern arises, as shown in Figure 3b. Here again we observe a spiral pattern, but it is by far very different from the boundary layer instability patterns described up to now. First, the spiral arms roll up the centre in the direction opposite to the faster disk: for this reason we call them *negative spirals* (blue region in the diagram of Figure 4).

Perhaps the most striking characteristic of the negative spirals is their very large growth time: when the onset is carefully approached from below, about 10 to 20 minutes are required for the negative spirals to arise. Such very slow dynamics strongly contrasts with the circles and positive spirals, which appear almost instantaneously when their threshold is reached. For this reason, a precise determination of the negative spirals threshold is a rather delicate work, that needs a very stable and controlled apparatus and... a lot a patience! Slightly further from the threshold, this growth time takes more reasonable values, of the order of one minute or a few seconds. Actually, it can be shown that this growth time diverges as one approaches the onset, a usual property for critical systems near a bifurcation point.

Perhaps the most striking characteristic of the negative spirals is their very large growth time

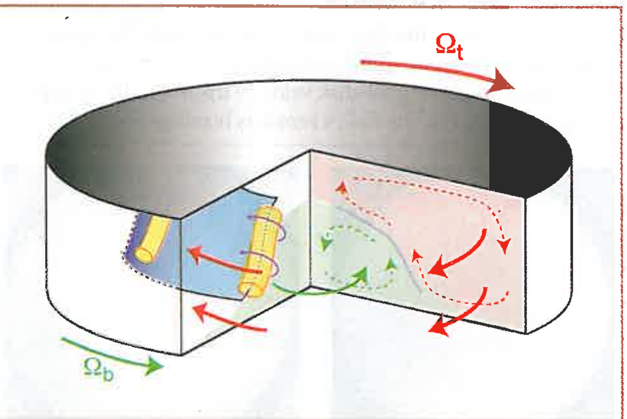
What happens now if the gap between the disks is changed? We can see that the morphology of the negative spirals strongly differs, from h=7 mm (Figure 3b) to h=20 mm (Figure 5a). For this new gap, the instability gives rise to a more complex structure near the centre of the cell, in the form of a circular chain of vortices surrounded by spiral arms. Moreover, the number of spiral arms is smaller in the large gap case: from 11 arms for the small gap, down to 5 arms in the large gap case (values down to 2 arms can be found for even higher values of h). This variation can be easily understood, if we imagine the spiral arms as vortex tubes, whose diameter is of order of the gap thickness h.



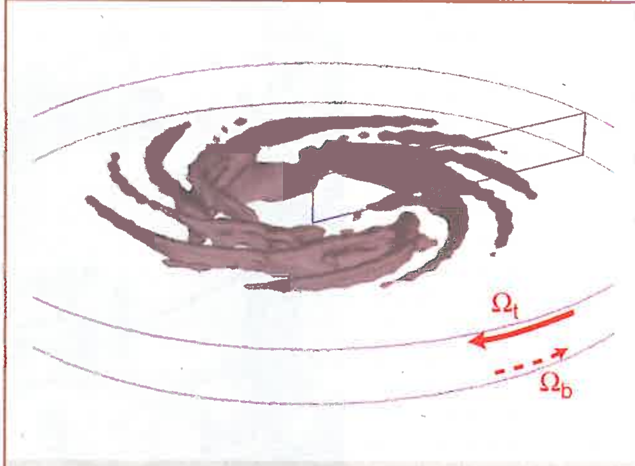
▲ Fig. 5: (a) Example of a 5-armed negative spiral pattern, observed for a large gap thickness (h=20 mm). This picture has to be compared to the equivalent pattern for a small gap, in Figure 3b. (b) Corresponding velocity field, as measured from Particle Image Velocimetry (PIV). Colors are coding the levels of vertical vorticity, *i.e.*, the 2D local rotation rate of fluid particles [8].

More insight into the physical mechanism responsible for the formation of this pattern may be obtained from the velocity field of the bifurcated flow. In the case of the large gap, this velocity field can be obtained by means of Particle Image Velocimetry (PIV). This non-invasive technique consists in measuring the distance swept by small particles seeding the flow between two successive images. The particles are illuminated by a pulsed laser sheet synchronised with a high-resolution video camera. In Figure 5b, obtained for the same angular velocities as in Figure 5a, we can see the circular chain of 5 vortices surrounded by the negative spiral arms, similar to the pattern visualised using the flakes [8]. The colours encode the levels of vorticity, *i.e.*, of local rotation rate of the fluid particles, from blue (counter-clockwise) to red (clockwise).

An important feature of this velocity field is the presence of an intense shear layer (in red), where strong vorticity is concentrated.



▲ Fig. 6: Schematic view of the shear layer instability between counter-rotating disks. Each disk tends to impose a centrifugal recirculation, dividing the bulk of the flow into two recirculation cells (red and green). At the interface between these two cells a shear layer takes place (in blue), that becomes unstable and generates nearly vertical co-rotating vortices (yellow).



▲ Fig. 6: Numerical simulation of the flow between counter-rotating disks. Negative spirals with 9 spiral arms can be seen. Data from O. Daube and P. Le Quéré [10].

This thin layer separates the outer part, rotating with the faster (upper) disk, from the inner part, where much lower velocities are found. The origin of this shear layer can be understood from the Figure 6. In the counter-rotating regime, each disk tends to impose its rotation to the fluid (full arrows), associated with a centrifugal flow (dashed arrows). The centrifugal flow induced by the faster disk, in red, recirculates towards the centre of the slower disk due to the lateral end wall. This inward recirculation flow meets the outward radial flow induced by the slower (bottom) disk, in green, leading to the formation of two recirculation cells. At the interface between these two cells a strong shear layer takes place. Such layer is prone to an instability, which leads to an azimuthal modulation and to the roll-up into individual co-rotating vortices [9]. This instability mechanism was first introduced in the simpler case of a linear shear layer by Lord Kelvin and Hermann von Helmholtz at the end of the XIXth century, and was aiming to explain the wave formation due to the wind stress on the sea surface [2].

...heavy computations are now feasible thanks to new generation of supercomputers

Our flow between rotating disks, although very simple, presents two classes of instability patterns, associated with very different physical mechanisms: boundary layer instabilities (circles and positive spirals), which have been studied for a long time in similar flow geometries, and shear layer instability (negative spirals), which have been first observed in our particular set-up between counter-rotating disks. The complexity of the observed phenomena is striking compared to the apparent simplicity of the flow geometry. This is a generic situation for systems governed by nonlinear equations, among which the hydrodynamics systems play a central role. The basic solutions, usually simple because associated with a high degree of symmetry, are replaced by much richer patterns, that may coexist and interact together (see the dashed regions in Figure 4). The flow between two coaxial cylinders, of practical importance in rheology, is another example of very simple flow with a large variety of instability patterns and transitions towards turbulence.

The new class of instability revealed in our experiment has motivated a numerical study of the flow between counter-rotating disks. Such simulations are very expensive in terms of computational time: because of the very large growth times, the full 3D Navier-Stokes equations have to be simulated over a very long time. This work has been carried out by Olivier Daube, of laboratory CEMIF (Evry, France), and Patrick Le Quéré, of laboratory LIMSI (Orsay, France). Figure 7 is a visualization of the flow between counter-rotating disks separated by the distance h=20 mm, where the surfaces of iso-vertical velocity are shown [10]. This quantity traces the rolling up of the streamlines in the radial and azimuthal directions, and clearly exhibits a spiral pattern in excellent agreement with the ones observed experimentally.

Such heavy computations are now feasible thanks to new generation of supercomputers, and opens new and exciting perspectives in the understanding of complex flow phenomena. Among the situations of considerable practical interest are the turbomachines used in power plants or aeronautics engineering. This latter application involves huge rotations rates (more than 10 000 rpm), and accurate modelling of the turbulent phenomena present at small scales are clearly needed for such numerical simulations. In this context, the excellent recent agreements between experiments and numerical simulations are encouraging for the understanding and modelling of turbulence under strong rotation.

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High school students' exposure to modern particle physics

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Modern physics of the 20th and 21st century is hardly taught in science courses at high schools in Europe. Nevertheless, introducing results of modern physics research at high-school level could positively influence the students' perception of today's role of physics, and along with it, their general interest in physics. On the other hand, discussing modern physics in too much detail or on too high a level might have the opposite effect. Therefore, appropriate topics and teaching material have to be identified and developed in close collaboration between scientists and educators. An evaluation is needed to assess the success and to optimize both the material and its channels of distribution.

Like all of us, young people from time to time seek to answer fundamental questions, such as what are we made of, where did matter come from, how did the Universe begin and how will it end? This would suggest that particle physics and cosmology is a topic of modern physics well suited for high schools. In recent years a wide range of material for the public understanding of particle physics has been developed, e.g. UK masterclass workshop exercises [1], German web-based teaching systems [2], or the material described by K.E.Johannson in this issue. This article will focus on evaluations of such material with 16-19 year-old high-school students, recently performed at several locations in the UK and Germany. The spectrum of these events covers visits to exhibitions, "masterclasses" at universities, and particle physics in the classroom as a part of the curriculum, thus ranging from mainly passive visits, through active but short-term workshops, to longer-term science teaching and assessment.

"TESLA—Light of the Future", an exhibition on particle physics and more

From 16.1. to 17.2.2002 a "journey to the origin of matter" and "insights into the most tiny dimensions of life" were offered to about 22,000 visitors to an exhibition in the centre of Berlin [3]. Among them were more than 70 school classes, mostly from grades 12 and 13 (17-19 year-olds). The topics of the exhibition were the forefront of particle physics research with the planned Electron-Positron Linear Collider TESLA, along with the exploitation of its accelerator technology for a Free Electron Laser light source with unprecedented brilliance, having applications in chemistry, biology and material science. The exhibition was realized by DESY in the basement of the Volkswagen Automobile Forum where original equipment, models, posters, videos, and hands-on material were displayed in an area of 700 m^2.

More than 250 students were interviewed [4] after the visit, which included an introductory talk and a tour guided by particle physicists or Ph.D. students. On a scale from 1 to 5 the students ranked particle physics to be quite interesting, with an average score of 3.9 for the male and 3.6 for the female students. Although this score is less enthusiastic than the one from the other visitors (4.3 and 3.9, respectively), the general physics interest of the students increased about 8% more than that of the public: 45% of the male and 52% of the female students responded that their general interest in physics had grown strongly during the visit. This increase was highly correlated (correlation coefficient ρ=26%) to the ability of the guides to stimulate this interest. In turn, the success of the guides was very much facilitated (ρ=42%), if the physics interest of the students before the visit was already large. Independent of the guides' explanations, those students who knew least about particle physics before coming to the exhibition gained most in their general interest in physics (ρ=–13%). Regarding the type of presentation, apart from the guides, the 3-dimensional models, the videos, and the eight hands-on stations (Figure 1) were the clear favourites. All visitors agreed, that only a few things could be improved, and that even more hands-on exhibits would be very good.

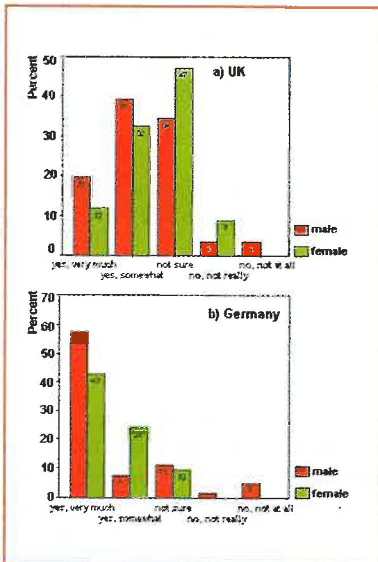
▲ Fig. 1: "Hands-on" activities at the TESLA exhibition in Berlin:
a) accelerating a ball surfing on a wave with adjustable phase velocity
b) focussing an electron beam using quadrupole magnets

Particle physics masterclasses

For about 6 years particle physics groups at universities in the UK have invited 17-18 year old high school students to spend a day in the university [5], for a mixture of talks and practical computer activities [1], such as identifying particles. After relatively little training the students are able to recognize various types of particles through real images of their tracks on computer, in a way that mirrors exactly the activities of working particle physicists. Deep insights into the properties of elementary particles, such as the universality of the three types of leptons in Z^0 decays, can be obtained this way.

This idea has begun to be copied by German universities, using translations of the UK material [1]. In the UK, whole A-level science classes, for which some particle physics is part of the physics curriculum, usually attend together with their teacher. The German masterclasses ("Schnuppertage") are based on voluntary attendance by individual high-school students. Particle physics, apart from radioactivity, is generally not taught in physics classes at German schools.

The evaluation [4] was based on interviews at London and Bonn masterclasses with a total of about 100 students, each. Although the basic knowledge was similar at both locations, quite substantial differences were observed. The UK students found the masterclass program in general more challenging ("right level" UK: 42%, D:65%, "difficult" UK: 41% D:15%), and judged that they had increased their knowledge in physics more strongly, with an average of 3.9 on a scale from 1 to 5, compared to 3.3 in Germany. In contrast to that finding, the German students gained more general interest in physics. Even more pronounced than at the TESLA exhibition, 39% of the male and 62% of the female stu-



◀ **Fig. 2:** Response to the question, if 17-18 year-old students would like to deal more often with modern physics in their science classes, after having taken part in a particle physics masterclass at universities in the UK (a) and in Germany (b)

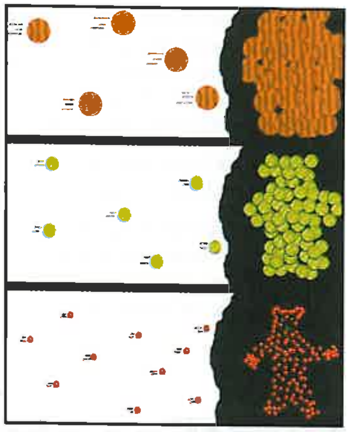
dents of the Bonn masterclasses reported that their general interest in physics had increased strongly or very strongly, resulting in an average change of +2.4 and +2.7, respectively, on a scale from 0 to +4. In the London masterclasses a somewhat smaller increase was observed with +2.1 and +1.8 for the male and female students, respectively. Although the differences between girls and boys are statistically not very significant in this one question, a synopsis of all answers shows that on average the British girls were less enthusiastic than the boys, while in Germany the opposite effect was found. A further large difference between London and Bonn was that 34% of the British students would have liked to sacrifice some lectures in favour of more computer activities, while only 17% would have preferred to do so in Germany. As a result of the particle physics masterclasses, the German students in particular would like to deal more often with modern physics at school (Figure 2).

Particle physics in the high school curriculum for 15-16 year-old students

At German High Schools the students have to select their spectrum of subjects for their last two or three years themselves. A nation-wide survey in the year 2000 [6] has revealed that 2 in 3 of the students drop physics at the earliest possible opportunity, which in some of the states already happens after the 10th grade, at an age of 15 to 16 years. The only modern physics topic the students are confronted with by that time is the physics of nuclear reactors. Recently, several "first theses" of student teachers at Bonn university tried to broaden the spectrum of modern physics available for this age [2]. Teaching concepts of particle physics [7], and of the impact of particle physics on medical applications and cosmology [8] were developed, supported by interactive Web Systems (Figure 3), and accompanied by background information for the teachers. For a trial conducted in four 10th grade classes, teaching units ranging from 8 to 26 lessons, depending on the available time, were formed by merging the previously existing material on nuclear physics with the new particle physics material...

The teachers who carried out the respective units clearly concluded in their evaluation [10,11] that modern particle physics can successfully be taught to students of this age. Written and oral tests of the students showed no difference in the distribution of grades compared to standard subjects of the curriculum. On a scale from 1 to 5, the students rated their interest in this teaching unit very highly with an average of 4.0, with more than half of the students of the shorter units demanding more time for questions and deeper discussions. While the level of difficulty was judged completely appropriate, three quarters of the students criticized a lack of practical experiments which could not be compensated by the few interactive simulations in the supporting Web system. The immediate influence of this modern physics teaching unit on the general physics interest of the students remained very small, according to their own judgement, but about 80% of the students would support the idea that particle physics should become a part of the 10th grade physics curriculum.

▶ **Fig. 3:** Example of an illustration about resolution power for 15-16 year-old students in Germany: A structure in a cave is resolved best using the smallest probes, from [9].



Summary

About 25 years after the Standard Model of particle physics was established, scientists and educators have started to develop material suited to bring high school students in contact with the fascinating world of the fundamental building blocks of matter and their interactions. Evaluations have proven to be helpful in revealing strengths and weaknesses of the projects, in order to carefully adjust the material and the ways of presentation to the respective target group. The most difficult, but perhaps most rewarding, effort will be to implement this exciting field of contemporary physics as a part of the curriculum for 15-16 year old high school students.

Exposure of young people to modern physics, such as particle physics and its technological applications, is possible in a broad range of channels from exhibitions to classroom lectures, and can contribute to promoting the general interest of young people in physics.

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Frontline physics for teachers and students

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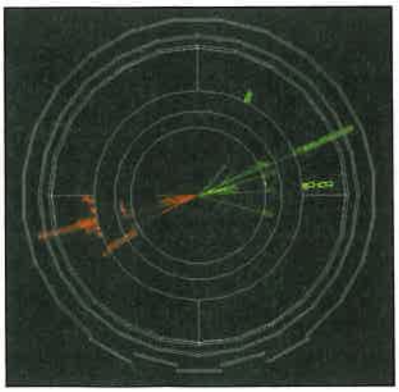
Today's research projects can enrich physics education at school and complement the traditional way physics is taught. The projects described here explore the Milky Way and the most fundamental level in the interior of matter with the aim to increase both the understanding of and the interest in natural science. Research councils and other financing bodies are starting to appreciate the importance of this type of education projects for the future of science, but a lot still remains to be done.

The world of particles

With the Hands on CERN education project [1, 2] the students can "take part" in a modern particle physics experiment at the forefront of scientific research using scientific data transmitted via Internet. The primary aim is to show particle collisions from the physics frontline and to stimulate interest in science and technology. Hands on CERN complements the traditional physics education and confronts the students with contemporary physics and technology at its most fundamental level.

With high energy particle collisions it is possible to study the smallest building blocks in Nature—the quarks and the leptons. Some of these build up the world we see around us, some existed naturally only at the beginning of time, the Big Bang, but are now produced in high energy collisions at a few large physics laboratories in the world.



◄ Fig. 1: The production in an e^+e^- collision at 91 GeV at the LEP collider of a Z^0 particle that instantly decays into a quark and an antiquark, which give rise to sprays of particles that are detected in the DELPHI detector.

The scientific data come from the DELPHI experiment [3] at the Large Electron Positron Collider (LEP) at CERN. Until year 2000 LEP was producing high energy collisions between electrons and positrons. During the first phase of LEP the collision energy was 91 GeV and a single Z^0 particle was produced in the collisions (Fig. 1). During the second phase the collision energy was increased to around 210 GeV sufficient to produce WW and ZZ pairs. With these data virtually all components of the Standard Model, with the exception of the top quark and the Higgs particle, can be explored—the quarks and leptons, the gluon and the electroweak and strong interaction.

We often encourage the students to look at the Particle Adventure [4] to get an introduction to the world of particles. In order to make the students more familiar with elementary particles the web exercises are complemented with laboratory experiments. The classical Thomson e/m experiment and the Millikan experiment on the electron charge, make the students familiar with elementary particles and the manipulation of them with electric and magnetic fields.

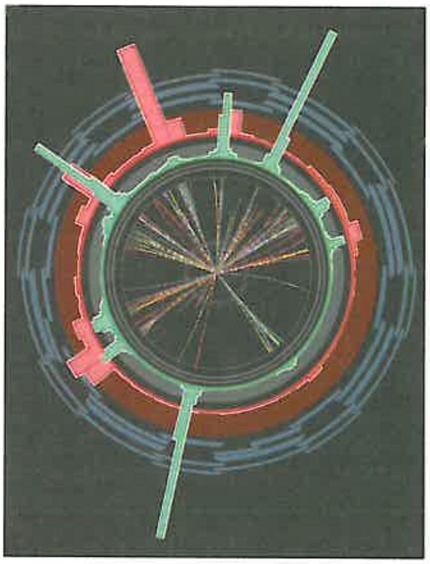
The structure of the Milky Way

It is not possible to see very far in the Galactic plane in the optical wavelength region. This is due to the absorption caused by clouds of dust that are distributed among the stars in the galaxy. This interstellar medium is however quite transparent to radiation from the well known 21.1 cm line in atomic hydrogen. This radiation makes it possible to study the distribution of hydrogen in our Galaxy and thereby study the spiral structure.

▲ Fig. 2: Students in front of the radio telescope with which they explored the Milky Way.

We used a small radio telescope with a 2.3 m diameter parabolic antenna to map the Milky Way (Fig. 2). The telescope is set to detect the 21.1 cm atomic hydrogen radiation. By measuring the Doppler effect in the received radiation one can measure the radial movements of the spiral arms relative to us and also calculate the distance from the observed cloud of hydrogen to the Galactic Centre. For these calculations we need to know our own position and speed relative to the centre of the Galaxy, but also the assumption that the tangential velocities around the Galaxy are practically constant outside the very inner part of the Galaxy. This project is described in more detail in [5].

The assumption of the tangential velocities being practically constant outside the central part of the galaxy has been experimentally verified for several galaxies, but is nevertheless quite surprising. The measured rotational velocities indicate the presence of matter in addition to the matter of the luminous stars. This unknown type of matter, the dark matter, seems to be a very important component of our Universe. One possibility is that the dark matter is composed of supersymmetric particles. These particles could be detected in the high energy particle collisions either at the Fermilab Tevatron or the future proton collider at CERN, the LHC. There experiments like ATLAS could very well discover the hypothetical dark matter particle of the Universe (Fig. 3).



◄ Fig. 3: A simulated proton-proton collision at 14 TeV at the LHC collider. At the collision a large number of particles are produced and detected by the ATLAS detector.

Astronomy and particle physics

For several years we have organised courses in astronomy and particle physics for 17 – 18 year old secondary school students. The students either studied the differential rotation of the Milky Way or the intricacies of high energy particle collisions. Plenary talks by scientists in astronomy, cosmology and particle physics were given to both classes to make all the students familiar with the different subjects and the fascinating connection between cosmology and particle physics. The combination of making their own measurements of the Milky Way with a small radio telescope, using scientific data from high energy particle collisions and having the Standard Model, the Milky Way and the Big Bang explained by scientists created an attractive and fascinating course in contemporary science.

▲ Fig. 4: The Stockholm House of Science on the campus of the AlbaNova University Centre.

The House of Science

Until 2000 this project took place at the Science Laboratory [8] at Stockholm University, a laboratory devoted to teachers and students at school. This laboratory was for many years a platform for many projects in modern science [2, 5-8]. Since 2002 the Science Laboratory has become the Stockholm House of Science [9] (Fig. 4), at present devoted to astronomy, biotechnology and physics, and situated at the AlbaNova University Centre, a joint Stockholm University and Royal Institute of Technology centre.

Summary

During the research project the students realised that they could determine some of the most fundamental quantities in the Standard Model of microcosm and learn about the structure and dynamics of our own galaxy, the Milky Way. With scientific data, the right tools and instructors the students could explore fundamental processes in Nature normally only accessible to scientists. When planning future scientific projects it is essential to keep in mind the importance of promoting the interest in science at school and the role of scientific outreach activities.

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features

Sheet laser lightning in Prague

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In order to stop a painful brain drain and to make the domestic research career more attractive for young physicists, the Czech science policy makers promote natural centres of excellence formed around groups of the most experienced scientists or around key research facilities. In the year 2000, several selected Czech Research Centres gained substantial additional financial support from the Ministry of Education, Youth and Sports of the Czech Republic. One of them, the Laser Plasma Research Centre in Prague, has already gained a good reputation throughout laser Europe. Its key laser facility, the Prague Asterix Laser system (PALS), lists now among the European Major Research Infrastructures. This first international multi-user high-power laser system in Europe's newly associated countries, and a European LASERNET member, celebrated recently its second anniversary.

The PALS's predecessor, the German Asterix IV high-power iodine laser, had already gained a good renown among the European laser plasma research community in the first half of the nineties of the last-century. Developed at the Max-Planck-Institut für Quantenoptik in Garching by Munich and operated there successfully since 1991, the laser suddenly faced a serious decision about its further destiny in spring 1997. Since that time it turned out that saving it for further use was very wise, and that moving the laser to Prague was really a coup for its new mother institution, the Academy of Sciences of the Czech Republic (AS CR). Due to its unique features, several new options and some principal innovations, the reincarnated Asterix/PALS facility is enjoying now a permanently increasing interest of both domestic and foreign researchers.

The risky operation of the laser transfer to Prague began in late summer 1997, with an ambitious goal to put the giant laser into full operation again by spring 2000. At that time, very few people believed that the tight schedule of all the necessary operations could be maintained. For instance, in the Czech Republic no suitable housing for the laser was available. It had to be projected and built first. Nevertheless a rather small group of Czech enthusiasts managed to cope with all the obstacles that came up and fulfilled the virtually impossible. A new laser hall for the laser grew up almost overnight, the reassembling of the laser was finished and its operational tests started in late 1999, and the laser reached its full parameters in May 2000. In September 2000, the laser started to offer its beam time to European physicists.

PALS is a single-beam kilojoule-class pulsed laser. Its kilojoule output, together with a relatively long pulse (~400 ps), make it a powerful driver for various practical applications. Unlike the other, mostly solid-state, high-power lasers in Europe, PALS has an iodine gaseous medium, which gives it some unique advantages. It generates a high-quality infrared beam of an almost flat intensity profile. A single-beam configuration of a chain of laser amplifiers permits the variation of the output beam energy over two orders of magnitude. The fundamental frequency of the beam (1315 nm) can be up-converted to the 2nd, 3rd and even to the ultraviolet 4th harmonics. The laser pointing is stable over two-months, its operation is relatively cheap. Due to all the above features, PALS is almost ideally suited for the basic and applied studies of laser interaction with matter at power density levels ranging from 10^{14} to 10^{16} W/cm^2.

a rather small group of Czech enthusiasts managed to cope with all the obstacles... and fulfilled the virtually impossible

Although the PALS laser still keeps the original configuration of the former Asterix, it has been upgraded by new beam lines and diagnostics options. A new original-concept twin target chamber with several beam focusing assemblies has been designed in co-operation with French laser specialists, which permits the performance of even the most sophisticated laser plasma experiments, such as development and applications of plasma soft x-ray lasers.

Current PALS main research priorities are aimed at exploiting the laser plasma as a source of soft x-radiation, of highly charged ions, and at relevant scientific applications. As a users facility, PALS is offering its beam time to both domestic and foreign researchers. Since September 2000, the laser is being intensely exploited by scientists from France, Germany, Italy, Poland, Russia, Slovakia, and The Netherlands. Eighteen research projects in total, proposed both by domestic and foreign research groups, have been already performed at PALS during the years 2000-2002, and a number of new ones are planned. The research projects for PALS are peer-reviewed by an international User Selection Panel, the best projects for EU member and newly associated states being recommended for support by the European Commission's 5th Framework Programme (Transnational Access to Major Research Infrastructures and INTAS projects). Most of the projects already supported follow two main research lines: development of ultra-bright x-ray sources, of the soft x-ray

▶ **Photo:** The PALS twin target chamber. Josef Krasa (PALS ion group) adjusting diagnostics for an experiment with laser ion sources.

▲ Photo: View of the chain of PALS laser amplifers, with an oscillator block in the foreground.

lasers in particular, and development of laser plasma ion sources. The diverse PALS research programme includes also various basic laser plasma studies, such as x-ray spectroscopy, multi-frame laser interferometry and soft x-ray dosimetry, and also investigation of laser-generated shock waves and gas discharges.

As for the current PALS x-ray projects, their main motivation is a number of emerging applications of laser x-ray sources in science and (high) technology. Recent research highlights include development and application of a highly coherent double-pass XUV laser based on Ne-like zinc, x-ray contact microscopy of living biological objects, and encouraging results on x-ray-induced ablation. Undoubtedly, the greatest success for the PALS laser laboratory is last year's launching of an extremely brilliant pulsed zinc soft x-ray laser, by a group of Czech and French scientists headed by B. Rus (PALS) and G. Jamelot (LSAI Orsay). High-quality x-ray interferograms, obtained with the PALS x-ray laser in a subsequent application experiment – in the first successful experiment of this kind – testify not only to a high spatial coherence of the x-ray laser beam, but also to the high qualities of the PALS laser used as driver. The output power of the PALS x-ray laser is probably the highest ever achieved in laboratory, at least in the soft x-ray region in question. Another group of the laser x-ray sources studied at PALS, namely point sources of non-coherent x-radiation with characteristic photon energies ranging from tens up to hundreds of eVs, is finding its application e.g. in soft x-ray microscopy for biologists, or in extreme ultraviolet lithography, long called for by the electronics industry. Another great challenge consists in exploiting ultra-bright laser x-ray sources in future nano-technologies, for instance in nano-machining of various materials or in controlled modification of their surface structure.

The main goal of the PALS ion projects is to develop flexible laser ion sources for industrial ion implantation, and powerful ion injectors for future particle accelerators. The laser ion sources (LIS) generate ions with practically any atomic number, in particular heavy ions with a very high charge ($Z > 50$), and with energies ranging up to several tens of MeVs. The high ion energy, high current values and partial directionality of the generated ion streams make the LISs very attractive in competition with conventional ion sources.

It not possible to recount here all the experiments performed or to be performed at PALS and, thus, we have to refer just to a regularly updated list of the PALS projects and their outputs at the PALS homepage www.pals.cas.cz. Nevertheless, let us mention at least one more project, the goal of which is to simulate the effects of impacts of extraterrestrial bodies and of the radiation of the young Sun in the deep past of the solar system with, perhaps, some relations to the origin of life. In these experiments the PALS laser beam is used for plasma generation in a mixture of gases, the composition of which is similar to that of early planetary atmospheres. A number of organic compounds have been already found in the investigated samples.

In order to meet the requirements of even the most exacting future projects, several substantial upgrades of the PALS performance are being prepared, which include e.g. application of the elements of adaptive optics, replacement of the original iodine oscillator by a solid-state based one, and, most importantly, implementation of the optical parametric chirped pulse amplification (OPCPA) technique. A new compact solid state front-end will enhance the variability of the laser pulse width and will make it possible to increase the pulse repetition rate. The controlled feedback adaptive mirrors inserted in the laser beam path are intended to remove some residual wave front aberrations, and to further improve the beam quality, in order to achieve focal power densities of around 10^{17} W/cm^2.

The OPCPA implementation, for which the PALS iodine laser is particularly suitable, should make it possible to boost the PALS power up to the ultra-high-power domain (10 TW – 1 PW). In a projected system, the seed signal pulse with a sufficiently broad spectrum will be generated by a minute Ti:Sapphire oscillator and chirped in a pulse-grating stretcher. Non-linear crystal amplifiers (LBO, KDP), pumped by the blue (3ω) PALS beam, will parametrically amplify the chirped pulse to a level of 100 J. The optical compression of the chirped pulse is expected to compress the output pulse into the femtosecond domain (20-40 fs). This would result in a power density on the target exceeding even 10^{21} W/cm^2.

Direct application of OPCPA at PALS would reduce significantly the available beam time, which is severely limited now, owing to all the current PALS user activities. Therefore a new, smaller-scale, hybrid laser SOFIA (λ=1315 nm) is being currently built. SOFIA is an acronym for a hybrid laser chain, in which a nanosecond laser beam, generated by a solid-state oscillator, is amplified in a gaseous laser medium of iodine photodissociation laser amplifiers (Solid-state Oscillator Followed by Iodine Amplifiers). The upgrades tested with the SOFIA laser will not only speed up their implementation at PALS, but also reduce the final costs. The SOFIA laser is scheduled to run before the end of 2003. If successful, it will take over the role of PALS in the first step to petawatts.

Having successfully passed its first baby steps during the first two years of its operation, the Prague Asterix Laser System has grown up into a flourishing adolescent. Being more mature with each laser shot, it stands already on its own feet, having become a recognised partner of its laser pals. Looking around now, PALS has chosen the way leading to ultrahigh power in general and to ultra-bright x-ray sources in particular. This way will no doubt be far from easy and will be hard to accomplish without a continuing mutually-advantageous co-operation with European partners, and also with partners outside Europe. Nevertheless, the die is cast. For the sake of all your present and future users, sail in PALS!

New challenges in statistical and nonlinear physics

Jean Pierre Boon[1] and Maxi San Miguel[2]
[1]University of Brussels, [2]IMEDEA/Palma de Mallorca

On the occasion of the board meeting of the Statistical and Nonlinear Physics (SNP) Division, a colloquium focusing on some *New Challenges in Statistical and Nonlinear Physics* was organized and chaired by Maxi San Miguel (Palma, Spain), chairman of the Division. Two members of the SNP board presented lectures on the "Statistical Physics of Biocomplexity" (Peter Hänggi, Augsburg, Germany) and on "Reactive Processes in Chaotic Flows" (Tamas Tèl, Budapest, Hungary). A discussion session was also held where Peter Richmond (Dublin, Ireland) introduced the subject "Risks and Complexity" in the context of Econophysics, followed by Roland Ribotta (Paris, France) who discussed the needs for better "Visibility of Nonlinear Physics". The session closed with a short presentation by Jean Pierre Boon (Brussels, Belgium) on the perspectives of Tsalis' theory of "Nonextensive Statistics".

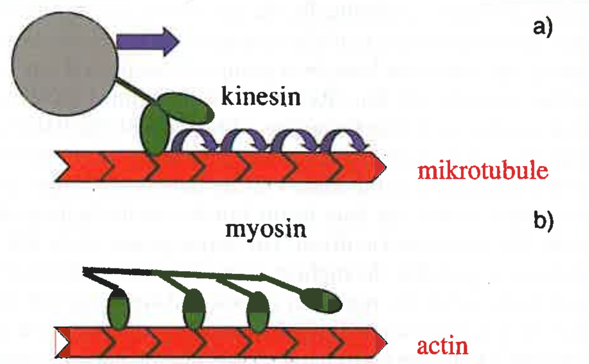
Biocomplexity

Biology and physics share common ancestors. Progress in the methods of statistical physics and the development of new physical tools and various ingenious experimental techniques has triggered dramatic progress in the field of biophysics. Likewise, the two fields have fertilized each other repeatedly over the last decades. Most importantly, the complexity of biophysics has inspired new developments in physics and chemical physics. In his talk Peter Hänggi, from the University of Augsburg, focused on some recent biophysical problems that attract the interest of many statistical physicists. Foremost, biological cells contain nanoscale machines that exhibit a unique combination of high efficiency, high reliability and recognition features and self-assembly properties (see Fig. 1). In particular, these biological machines transport material and perform work in a noisy environment. Likewise, this concept can be carried over to physical micro- and nano-machines which pump, direct and separate particles, and alike, most efficiently, both in the classical domain and in the quantum regime, e.g. in electron pumps. This in turn underpins the constructive role of noise for the amplification and enhanced detection of weak information-carrying signals (Stochastic Resonance in Biology [1]) and directed transport of cargo (Brownian Motors in Biology and Physics [2]). Quantum statistical physics enters biological complexity as well at the interface of electronic transport processes and the interaction with light. In this context, physicists and chemists are becoming increasingly interested in the electronic properties of the "molecule of Life", the DNA. Hänggi commented on the present lively debate as to whether quantum electronic transport in DNA behaves more like a good molecular wire or, more likely, whether DNA behaves more like a good insulator.

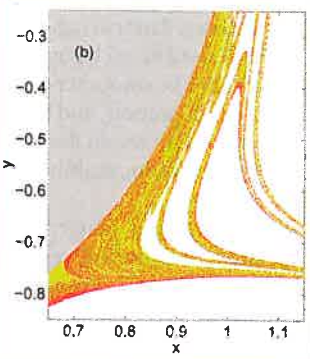
Reactive Chaos

In his presentation, Tamas Tél, from the University of Budapest, discussed recent developments in dynamical systems theory, chemical kinetics and population dynamics, showing that the outcomes of chemical or biological reactions in flowing media might be completely different from those taking place in homogeneous systems [3]. In particular, the product distribution is often not compact but filamental, and the productivity becomes strongly enhanced. This effect is highly relevant in environmental problems such as atmospheric ozone depletion [4] and plankton blooms in oceans [5], where the large scale flows are approximately two-dimensional.

The origin of this novel behavior is the typically chaotic motion of the advected particles in time-dependent—in the simplest case periodic—flows [6]. As a consequence, even inert particles are distributed along (moving) filamental patterns which turn out to exhibit fractal properties. Active particles are then distributed in narrow bands around these filaments at some fractal dimension $1 < D < 2$, where D is independent of time. The reaction takes place along the perimeter of the region covered by these particles. Hence the rate of change of the active particles number n turns out to be proportional to $n^{-(D-1)/(2-D)}$ [7]. This means that the kinetic equation contains a singular productivity term: a power law with a negative exponent. In the presence of an outflow from the region of observation, the loss due to the outflow and the gain due to the reaction lead to the appearance of a chemical or biological steady state after some time. The product distribution then stays around (moving) fractal filaments and the average value of the particle number becomes time-independent. In other words, in spite of the chaoticity of the advection dynamics, the chemical or biological process is regular in time-periodic flow, and it is governed by a fixed point or a limit cycle attractor.



▲ Fig. 1: Sketches of microtubules and actin filaments from the basic scaffolding of cells are depicted. The motor proteins kinesin and myosin are responsible for material transport and muscle motion. a) A kinesin molecule transports cargo along the microtubules by alternate binding and unbinding of the two heads. It is an example of a processive motor with a high duty ratio; i.e. a high ratio of time spent in the "bound" state and the time interval "bound plus unbound". b) In contrast, muscle contractions are caused by aggregated myosin molecules; the latter biophysical motor is an example of a nonprocessive Brownian motor. The motor heads of the myosin filament can bind effectively only in a cooperative manner to the actin filaments. Unbound heads fluctuate freely around their equilibrium positions. By preferentially binding at an angle in a forward direction, directed motion occurs.

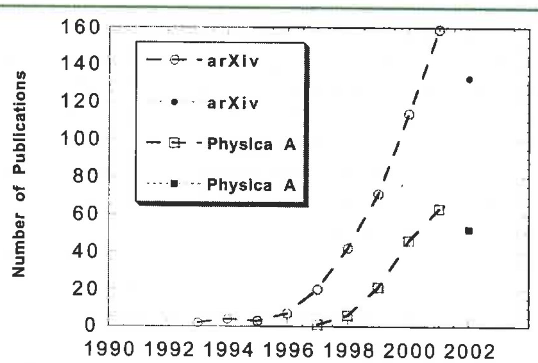


◄ **Fig. 2:** Snapshot of the steady-state product distribution in the wake of a circular obstacle in a time-periodic two-dimensional flow (Figure taken from [8]).

Figure 2 shows the steady state product distribution in the wake of a circular obstacle (say, an island) in a time-periodic two-dimensional flow. Two different reactants (red and green) live on the white background available everywhere in the flow. Red and green do not interact with each other directly, but compete for the white food. The figure clearly indicates that both red and green are present along fractal filaments (of dimension $D = 1.6$ in this case), as a consequence of the singular productivity term mentioned above. In the traditional theory of well-mixed reactions this setup always leads to the extinction of either Red or Green. The result, as emphasized by Tamas Tél, thus contributes to the understanding of why several plankton species can coexist in natural aquatic environments [8]. It clearly indicates the general feature of time-dependent flow: the filaments emerging due to chaos of the passive advection problem act in the reactive case as dynamical fractal catalysts and thus enhance the global production rates.

Econophysics

Econophysics has been coined as a term to describe the branch of physics that applies Statistical Physics to problems concerned with financial risks, a branch that grew out of the merging of ideas and methods of Statistical Physics and concepts and problems in Economics. The involvement of physicists in these areas is not new. Blaise Pascal, the celebrated mathematician, physicist, philosopher and sometime gambler, earned immortality for his unique contributions to the theory of probability in the 17th century. Edmund Halley, who discovered the comet now named after him, showed how, detailed records of births and deaths could be used to compute life expectancies and proceeded to make the first detailed mathematical analysis of the valuation of annuities published in the Transactions of the Royal Society in 1693. Newton and Gauss also tried to theorize financial speculation. The more technical connection between stochastic theory (random walks) and financial analysis dates back to Louis Bachelier, who was a student of Henri Poincaré's, when he developed a *Théorie de la spéculation* in his thesis presented at the Sorbonne in 1900. Bachelier's work, which was received with extreme skepticism at the time (even Poincaré was rather critical about his student's views) and had been forgotten for more than half a century, is nowadays considered as a milestone in Econophysics. Econophysicists consider as another milestone Mandelbrot's observation of power-law scaling in commodity markets as described in a paper published in 1963. Notice that at that time, economists were already running computer simulations of financial markets models. But it might well be that early models in modern quantitative financial analysis were stimulated by the work of physicists such as Osborne who in the late 1950's rediscovered the Brownian motion signature in stock market dynamics. And a major achievement in the field was the early 1970's work of Black and Sholes and of Merton whose model casts the option pricing problem into a diffusion type equation most often referred to today as the Black-Sholes equation.



▲ **Fig. 3:** Annual number of articles in the field of Econophysics according to papers deposited on Los Alamos archives or published in Physica A; dark symbols refer to 2002 data but until Oct. 31 (data compiled by Marcel Ausloos).

What is new is the intensity with which physicists today are now applying concepts from Statistical Physics such as ideas of scaling, universality, game theory and agent models to practical issues such as exchange rate fluctuations, the movement of stock prices and financial crashes, and portfolio management. The papers now being published (see Fig.3) span wider areas such as consumer choice and trends, business cycles and the evolution of organisations that are also of interest to social scientists and managers [9].

All these topics form the central theme of the very successful series of meetings organised by the SNP Division and concerned with the application of physics to financial analysis (contact marcel.ausloos@ulg.ac.be). Following the meetings in Dublin, Liége and London, the 4th meeting in the series will be held in Warsaw (November 2003) at the Warsaw University of Technology (For details, contact Janusz Holyst at jholyst@if.pw.edu.pl).

In addition a new COST action (COST P10) is expected to begin later this year. Physics of Risk will be of interest to those interested in the application of statistical physics, agent models and networks to not only financial risk but other areas such as health where the tools of physics can be usefully applied. Colleagues interested in joining the list of participants should contact Peter Richmond at richmond@tcd.ie.

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[9] Both the UK Institute of Physics and the German Physical Society have new subject groups devoted to these areas.

European workshop on Multimedia in Physics Teaching and Learning

Paolo Bussei and Silvia Merlino, INFM, Unity of Parma, Italy

The 7th workshop on Multimedia in Physics Teaching and Learning (MPTL) was held from 22-24 September, at Parma University, Italy. It focused on new trends and research results as well as on the presentation of review talks illustrating experiences gained while developing, testing and applying devices in multimedia and computer aided physics teaching and learning in Europe. Special attention was given to standardisation and exchange of resources between the different projects, highlighting the importance of transportability and the multilingual translation of multimedia products. Multimedia material for teaching Quantum Mechanics was presented and there was a multimedia poster session.

Contributions

Organised by the local Research Unit (Public Awareness and Didactics Group) of the *Istituto Nazionale per la Fisica della Materia* (INFM), the workshop is part of a series of workshops of the EPS Education Division. The scientific and organising committee was composed of Hans Jodl (leader of the MPTL workshop series), Urbaan Titulaer (member of EPS), Roberto Fieschi and Silvia Merlino (local organisers). It was attended by almost 50 participants representing more than 12 countries, with 22 active contributions and 5 invited speakers.

M. Belloni (Davidson College, USA), gave an overview of recent developments in the USA, focusing on multimedia based curricular materials and new distribution mechanisms at digital libraries. In his talk "Using Physlet to Teach Quantum Mechanics", he presented the interactive Physlet-based curricular materials produced to support the understanding of both quantitative and conceptual difficulties encountered by many students in this subject. Multimedia in Quantum Mechanics was the subject of all discussions during the first morning of the workshop.

O. Tommasi (INFMedia srl, Italy), addressed one of the most important aims of the workshop. His talk "Design of educational multimedia products in several languages", stressed the importance of multilingual issues in designing a multimedia product, from the points of view both of production and manageability. He discussed the most common problems that arise in designing a multilingual product, showing some strategies to minimise implementation efforts as well as to optimise effectiveness on the user side.

R. Roncaglia (INFMedia srl, Italy), spoke on Intelligent Tutoring Systems—educational interactive tools that use artificial intelligence to organise the learning environment according to the user's needs. ITS assesses knowledge, skills, and expertise of the learner and consequently provide explanations, hints, examples or demonstrations. He illustrated the main structure and functionalities of "Virtual Tutor", designed to train students in solving college level physics exercises, currently under development at INFM and Infmedia.

Finally, T. Duenbostl, (BG/BRG Ettenreichgasse, Austria) and L. Mathelitsch, (Inst. Theor. Phys., Graz, Austria), gave an overview of the ways multimedia could be used to teach physics in schools. Examples were taken from topics like computer-based experiments, simulations, games, virtual classrooms, and multimedia-supported textbooks. They also gave a survey on the actual implementation of these ideas in the the classroom, mainly within the Austrian school system.

Most participants presented newly developed material and their experience with the implementation. Representatives from Eastern Europe showed their respective multimedia projects.

The availability of computers and the internet is improving every day, meaning students are more aware of multimedia. The issue of how these tools are used becomes very important in physics education, as many participants emphasised.

The multimedia material presented covered all age groups from elementary school to university.

Discussions

Many topics were discussed during the workshop. It was unanimously agreed that the presentation is improving every year, showing the importance of these workshops and their format.

This year, for the first time, in addition to the standard poster boards, there was an interactive poster session with computers and internet access, allowing participants to see the different multimedia products themselves. This was welcomed very enthusiastically by the participants and represented one of the outstanding features of the workshop which could become one of the characterising aspects of MPTL workshops.

> an interactive poster session... represented one of the outstanding features of the workshop

The review talks sessions focused on new trends and research results as well as on the exchange of experiences of multimedia and computer aided physics teaching and learning in Europe. Participation was not as widespread as hoped, though there were many important contributions. We hope the review talk sessions will be an increasing trend in future workshops.

Today, multimedia technologies have shown their potential in the teaching of scientific subjects. Multimedia techniques attract students' attention, enabling an easier and more rapid process of learning. Physics and technology are often considered difficult subjects. The main reason is that it is not easy to introduce empirical laws and dynamic phenomena in textbooks. Interactive multimedia tools, with simulations and movies, are particularly effective in teaching physics.

Translating multimedia materials into different languages becomes an important issue and the language problem (transportability) needs to be considered from the outset.

Recently, universities and national research centres in Europe have been actively engaged in projects promoting scientific education, with very encouraging results. We are convinced that everyone would benefit from better collaboration among the various projects. At the same time, the present status of e-learning shows that further improvement must be made, in order to facilitate the access to knowledge through multilingual learning, and through functionally rich and easy-to-use learning systems. It is our intention, therefore, to involve other European countries, which do not have a tradition in multimedia, extending public awareness in the scientific and technological issues.

Most multimedia tools are aimed at higher education and teacher training. It is very important to use these tools in other subjects, including basic education, to make science and technology more appealing and address the scientific apathy crisis of young people.

The final discussion created guidelines for future MPTL workshops:

1. improve the interactive poster sections
2. give suggestion for next MPTL's principal topics: optics, thermodynamics, solid state physics or statistical physics.
3. strongly encourage people from different countries to present a status report on the MM situation in their universities and educational research centres
4. form a "referees group" for MM-material (for example, members of EUPEN and WORKING GROUP 5)
5. encourage people to present original uses of existing material available on the web, eg. non standard physics applets and simulations.
6. new projects should be organised in a modular form, suitable for different levels of application (university, school, in-service training, personal study)
7. choose a target group for school products, in order to compare the existing multimedia material devoted to this age group
8. address the language transportability issue during the planning phase of multimedia material.

Further information

For more information on MPTL 7, please visit:
http://informando.infm.it/MPTL/
MPTL8 will be held in Prague in September 2003
http://lucy.troja.mff.cuni.cz/~tichy/MPTL
More information on the MPTL series is available at
http://pen.physik.uni-kl.de/w_jodl/mmeuro.htm

◄ Photo: More than 60 representatives at the ground breaking ceremony of the new EPS office building.

EPS Council Report

David Lee, EPS Secretary General

The EPS Council met in Mulhouse on 28 and 29 March. Over 60 people attended, representing National Physical Societies, all EPS Divisions and Groups, Committees, IOMs and Associate Members. The Council meets annually to review the actions over the past year and to discuss future orientations for the Society.

Martial Ducloy, the outgoing President reported that the main activities of the Society have revolved around the Strategy Plan for Science adopted in 2001. The two main axes of the plan were to improve the visibility of the EPS within the physics community, and to raise the public awareness of the importance of physics. Among the actions undertaken within the physics community, the EPS organised 14 conferences in 2002, including the EPS 12th General Conference. Two new divisions, the Physics of Life Sciences, and Environmental Physics, created at Council 2002 had also begun their activities. To raise the public awareness of physics, the EPS has spearheaded an initiative to declare 2005 as the World Year of Physics. Broad based international support has been obtained, and the IUPAP General Assembly formally declared 2005 as the World Year of Physics in October. The EPS has also been successful in improving its contacts to the European Commission, and in providing expert advice on the Commission's policies.

At the Council meeting 2002, a working group was established to review the EPS constitution. A lively debate followed the presentation of the working group's conclusions, which centered on models for increasing the unit fee. A proposal will be made and discussed at Council 2004.

A short ground breaking ceremony for the new EPS office building on the campus of the Université of Haute Alsace was held on Friday afternoon. M. Troxler Schmitt, Deputy Mayor of Mulhouse, as well as G. Schulz, the President of the UHA were present, as were members of the local press. C. Rossel summarised the project in his report, stating that the building will be 340m^2, with a small conference room for up to 90 participants. The total construction budget is Euro 580000 financed by the French Government, the University, the city of Mulhouse and the region of Alsace.

The Council dinner was held at the Schlumpf National Automobile Museum. The museum has over 400 vehicles and the world's most extensive collection of Bugatti automobiles which delighted all members present. Prof. R. Carreras, the laureate of the 2002 EPS Public Understanding of Physics Medal made an elegant presentation to the delegates on the joys of physics.

◄ Photo: Outgoing EPS President Martial Ducloy signs ceremonial shovel.

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IAMP Prize

The International Association of Mathematical Physics (IAMP) announced the recipients of the Henri Poincare Prize sponsored by the Daniel Iagolnitzer Foundation. The Henri Poincare Prize recognizes outstanding contributions in mathematical physics and contributions that lay the ground for novel developments in this broad field. The laureates of the 2003 prize are
The recipients of the Prize are:

Huzihiro Araki, Research Institute for Mathematical Sciences, Kyoto University for his lifetime contributions to the foundations of quantum field theory, quantum statistical mechanics and the theory of operator algebras. His outstanding achievements at this interface of physics and mathematics are exemplified by his work on the structure of the algebra of local observables and its representations, collision theory, the variational principle in statistical mechanics and the notion of relative entropy for infinite quantum systems.

Elliott H. Lieb, Princeton University for his lifetime achievements in quantum mechanics, statistical mechanics and analysis. His work has encompassed the exact solution of the Ice model, an unceasing quest for a complete understanding of the stability of matter, Thomas-Fermi theory and quantum spin systems, and the discovery of a remarkable range of fundamental inequalities.

Oded Schramm, Microsoft Research for his contributions to discrete conformal geometry, where he discovered new classes of circle patterns described by integrable systems and proved the ultimate results on convergence to the corresponding conformal mappings, and for the discovery of the Stochastic Loewner Process as a candidate for scaling limits in two dimensional statistical mechanics.

Executive Committee Elections

Below is the composition of the Executive Committee following the elections during Council (27-28 March 2003)

Martin Huber	President
Martial Ducloy	Vice President
Peter Reineker	Treasurer
Chis Rossel	Secretary
Maria Allegrini	
Gerardo Delgado Barrio	
Hennie Kelder	
Dalibor Krupa	
Paul Hoyer	
Peter Melville	
Zenonas Rudzikas	

The European Physical Society would like to thank the outgoing members, D. Brown, K. Gaemers, and C. Zerefos for their hard work and dedication over the years.

World Year of Physics 2005

The WYP2005 Steering Committee met 27 March to discuss promotion and coordination. Available on the web site soon will be a list of proposed and planned activities around the world.

The Brazilian, French and Portugese delegations to UNESCO requested that UNESCO support WYP2005. The question will be deliberated at the UNESCO and UN General Assemblies in October 2003.

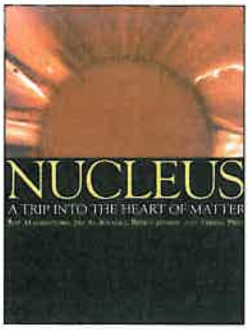
The organisation of the WYP2005 kick off conference is well under way. The European Research Commissioner, Philippe Busquin will be present and address delegates. The conference begins on Sunday 6 July. For more information see:

http://www.kfunigraz.ac.at/exp8www/wyp2005/main.htm

2002 Agilent Technologies Europhysics Prize

Author of *Quantum tunneling of the magnetisation in molecular nanomagnets* (EPN 34/2, page 41), Roberta Sessoli, along with Jonathan Friedman, Dante Gatteschi, Wolfgand Wernsdorfer and Bernard Barbara was awarded the 2002 Agilent Technologies Europhysics Prize for developing the field of quantum dynamics of nano magnets, including the discovery of quantum tunnelling and interference in dynamics of magnetisation.

BOOK REVIEWS



Nucleus: A trip to the heart of matter

Ray Mackintosh, Jim Al-Khalili, Bjorn Jonson & Teresa Pena
Johns Hopkins Univ Press, December 2001, 143 pages

Should we spend our time educating our fellow citizens about our science? It is difficult to answer no to this question. There is a deafening clamour from many quarters, arguing that we should because the public pay the taxes which foot the bill for scientific research or that we have a duty to educate the citizenry so that, in the polling booth, they can make the complex judgements any democrat faces. The counter argument is that to explain our science to the public it is often necessary, or is thought to be necessary, to distort it in the telling; to make exaggerated claims of abundant energy or wondrous cures for diseases. In short, we sell it as a panacea for all our troubles. This approach plays into the hands of those who see advances in science and technology behind every leukaemia cluster, every change in the weather, every outbreak of influenza etc. In other words science becomes the demon of the piece. Epidemiology is difficult enough without us having to spend a lot of our time explaining the random nature of statistical events in order to counter the wilder excesses of the press, who latch on to anything sensational. It seems that they feel no duty to present a reasonable view or to make a retraction or, in any way, rectify the errors they propagate. The essence of this side of the argument is that we should not provide them with the ammunition.

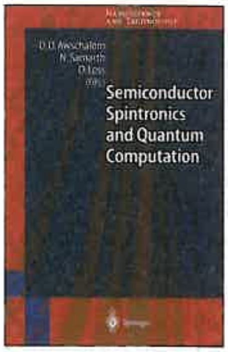
What is my view? It is an old-fashioned view but I believe we have a duty to tell the World about our work. I am very definitely in the pro corner. I have no doubt that we should try hard to explain our work to as many people as possible. We should try very hard to explain the meaning of risk as well as the excitement, the promise and the interest in our science. Our fellow citizens need to know the limitations to our knowledge as well as its extent in order to judge for themselves whether they should worry about the banner headlines in their newspaper or not.

The book reviewed here[Nucleus:A trip to the heart of matter] fits my view very well. It is very definitely aimed at educating the layman about the excitement and uses of nuclear science. As explained in the foreword by Nobel Laureate, Ben Mottelson, it attempts to 'use everyday language and exploit a wealth of informative pictures to explain the science and practical applications to a broad public'. Indeed Nuclear physics provides the ideal example of why we should write for a wide audience. Nuclear physics, in the minds of the public, is at once esoteric and outwith our normal experience and, at the same time, inspires deep-seated fears associated with nuclear weapons and the wilder tales of the effects of reactor waste products. There is no balance in that public view; no understanding that 30% of electrical power in the UK comes from nuclear reactors,for example, and that they do not produce greenhouse gases; no realisation that one-sixth of us in the so-called developed world will receive radiation therapy at some point in our lives; that nuclear reactions make the stars shine; that the chemical elements are created in nuclear reactions etc. This book seeks to redress that balance. Does it succeed? I have no clear answer but it is certainly a brave try. There is a lot to be admired about it. This is not a bloodless tale of abstract theories and complex experiments but a tale of real men and women mapping out the realities of our World. In words and pictures it brings out their genius and eccentricities. We see Wolfgang Pauli and Niels Bohr contemplating a top as they no doubt try to put flesh on the concept of particle spin. They may have been giants in their field but we feel their common humanity when we contemplate this picture. The authors and publisher have gone out of their way to make the book look good. It is chock-full of photographs of people and places and excellent diagrams that bring the subject to life. As a result it makes an excellent coffee-table book. If your office or department has a reception area it would certainly help to entertain visitors. Alternatively it would make an excellent bedside book for your guests at home. At the same time it makes a serious attempt to explain some of the mysteries of quantum mechanics as well as something of our knowledge of atomic nuclei. It seems to me to be pitched at just the right level for the intelligent layman.

It does not neglect applications of nuclear physics although, for my taste, I would have liked to have seen a greater emphasis on this aspect of nuclear science. Perhaps it is simply the result of three of the four authors being theorists. However, one should not carp too much. It makes the connection to astrophysics and the importance of nuclear processes in the early Universe and in stars. It reminds us of nuclear reactors, the potential of nuclear fusion and the applications of nuclear physics in medicine. It is here, I feel that the authors could have been more expansive. For example Positron Emission Tomography(PET) is mentioned but it would have been the ideal chance to show just what one can do with this technique. Imaging with PET and Nuclear Magnetic Resonance is an exciting area of research with some wonderful pictures of brain activity. Four sentences cover carbon dating. It deserves more, as do the many other applications of accelerator mass spectroscopy.

However I am carping again. I have met the authors, although not as a 'gang of four'. I can see their various enthusiasms in the book and I am pleased that they have produced this book. I have given it as a gift to several friends and several people I thought should know something of nuclear physics. This is sufficient testimony that I like it and can recommend it to you.

Bill Gelletly



Semiconductor Spintronics and Quantum Computation

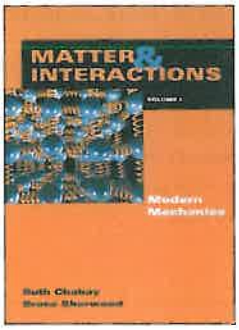
D.D. Awschalom, D. Loss & N. Samarth
Springer, 2002, 311 pages

The nine contributions presented in this volume provide an up-to-date account of the main fundamental aspects (experimental and theoretical) on the rapidly growing fields of "spintronics" (spin transport electronics or spin-based electronics) and quantum computation.This new electronics is based on the connection between the spin and charge degrees of freedom of the electron via the Pauli principle. A potential implication is that information can also be encoded in the electron's spin state. The applications foreseen include new semiconductor devices combining standard microelectronics with spin-dependent effects and the construction of quantum bits (qubits).

In the first six chapters, the reader can find extensive reviews on the recent experimental investigations: these range from the detection and study of spin-dependent phenomena in ferromagnetic semiconductors and their heterostructures, the transfer and spin injection across a ferromagnetic metal-semiconductor interface, to the description and detection of spin coherence in quantum wells and quantum dots. In particular, detailed accounts of the techniques and advances of the spin injection and transport are presented as well as the possibilities and the current limitations for electrical spin injection devices. An attempt to build the theory of spin coherence in semiconductors is given by the study of the dynamics of mobile spin in semiconductor via the interplay between spin and motion, and, spin and charge. All the recent developments in optical manipulation of spin coherence are discussed through numerous experimental approaches.

The last three chapters concern the role of the spin in the quantum information processing. Namely, a quantum computer proposal for quantum dots is pesented in detail; several schemes for the realisation of gates, measurement, state preparation, and, methods for producing and detecting the spin-etanglement of electronic EPR pairs are given. Finaly, by making use of the quantum dot spectroscopy, it is possible to create partially entangled pais which could be used in quantum key distribution systems.

Flora Koikiou, Laboratoire de Physique Théorique et Modélisation, Université de Cergy-Pontoise, France



Matter & Interactions Volume I: Modern Mechanics

Ruth Chabay & Bruce Sherwood
John Wiley & Sons Inc., 2002,
464 pages

The book, intended for science and engineering students, provides the mechanics and thermodynamics parts of a general physics course; albeit, with a genuinely innovative didactic approach- both conceptually and methodologically:

It focuses on the atomic structure of matter and the interactions experienced, underlining the fundamental principles functioning in the behaviour of matter and employing these principles for composing adequately simple and yet identifying models predicting or explaining the most important aspects of a wide variety of physical phenomena. This is interwoven with proposing and describing simple equipment experiments verifying or indicating theoretical treatments and is, also, supported reliably by inspiring and truly contemporary scientific computing algorithms, instructively designed and critically discussed within the main text.

Short exercises acquainting with the exact application of newly introduced concepts follow many sections of the text with their answers appearing at the end of the respective chapter. Furthermore, succeeding the summary of each chapter, come fully worked out example problems consolidating the comprehension of the conceptual content and illustrating the systematic application of the fundamental physical principles to real world composite states of motion and dynamical interdependence.

"Matter & Interactions- Volume I: Modern Mechanics" comprises 12 chapters followed by two appendices on vector and derivative basics and a subject index. After an exciting introductory chapter 1 on understanding and detecting fundamental matter interactions, an excellently paedagogical demonstration of the momentum principle in studying Newtonian motion with special emphasis on gravitational systems constitutes chapter 2. The atomic nature of matter is considered in chapter 3 for modelling the static and dynamic properties of a solid; energy conservation for a single particle and macroscopic systems being presented in chapters 4 and 5, with a convincing consideration of energy quantisation with respect to light—matter interaction, vibrational states, and nuclear energy levels appearing in chapter 6. Momentum and energy conservation application to multiparticle situations and nuclei is demonstrated in chapters 7 and 8.

Chapter 9 studies angular momentum conservation with respect to zero and non-zero net system torque, whereas chapter 10 discusses in an interestingly non-trivial manner the concept of entropy against the second law of thermodynamics, followed by chapter 11 considering molecule mean free path and channels of energy transfer within the framework of the kinetic theory of gases. Finally, chapter 12 presents with a welcome unusual focusing and detailed manner the energetic efficiency of engines running according to adequately varying thermodynamic cycles.

Overall, the book is a worth-experiencing real innovacy in the pedantic and systematic sense of disseminating university general physics mechanics for science and engineering students, permeated by a clever clarification of concepts and fundamental principles, productively suggesting student scientific reasoning, wisely preferring profound discussion of a non-superfluous number of carefully selected example problems rather than hurriedly touching a vast set of trivial or self-repeating exercises, and secured by a self-consistent and well received physical quantity symbolism in the text equations and representative vector code in the figures.

The reviewer, having coincidentally been following approximately the teaching philosophy of the book for the general physics course at the Hellenic Army Academy for almost a decade, is authentically enthused both to admit its pre-tested functionality and to propose its endorsement by other university curricula.

Professor Emmanuel A. Anagnostakis, Hellenic Army Academy, Athens, Greece.

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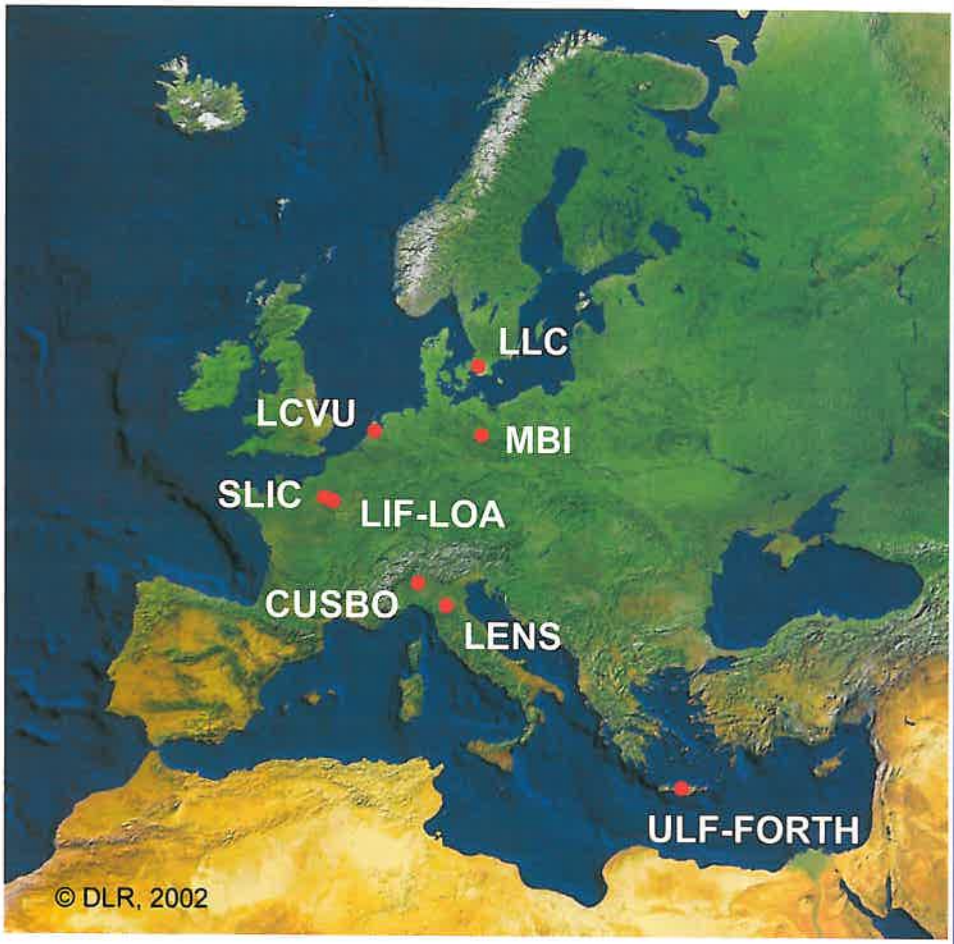

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The LIMANS III institutions are funded under the current IHP Programme of the European Union to provide access to researchers or research teams of Member States and Associated States. Within the cluster they offer state-of-the-art scientific laser equipment and research environments with a wide range of research opportunities, allowing for today's most advanced light-matter interaction experiments in broad regimes of power, wavelengths, or pulse durations. Access is provided free of charge; travel and living expenses are covered by the host institution.

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