# PARALLEL SYMPOSIA

**It is virtually impossible to give proper credit to the spirit and scope of trends in each of the specialist areas covered by the 13 parallel symposia at EPS-8. We have instead selected three which introduced a welcome draught of general appeal while emphasizing trends.**

## Laboratories In The Sky

"Waves In Plasmas (Laboratory and Universe)" (Session S 11)

In this period of intense solar activity that may account for our hot summer, and recent advances in stabilizing tokamak plasmas which may one day provide winter heat, it was appropriate that astrophysicists and plasma physicists came together to consider experimental and theoretical trends in the field of waves in plasmas from a multidisciplinary viewpoint. The stimulating programme was organized by the session chairmen (A.O. Benz and R.R. Weynants).

### A new spectroscopy

In both natural and laboratory plasmas, the geometry of the magnetic field is often spatially non-uniform so the plasmas are unstable. This feature shows up in the corona envelopes of stars: they are extremely active radiators of energy and they exhibit highly transient behaviour in the form of flares, just as tokamak plasma are prone to abrupt terminations in the plasma current. MHD waves in the plasmas play a key role and one expects that the spectral theory of MHD waves will provide a unifying theory for instabilities.

By analogy with atomic spectroscopy, the spectrum of waves depends strongly on the "potentials" (magnetic field and pressure). **J.P. Goedbloed** (FOM, Nieuwegein) consequently argued that new diagnostic techniques for laboratory plasmas, together with satellite observations of solar and other astrophysical plasma, will give birth to a new field called MHD spectroscopy for probing the potentials. Meanwhile, several phenomena in plasma are being modelled using MHD theories but the predicted structure is so rich in detail that it will take time to obtain experimental confirmation.

### Plasma waves in space — the main problems need their understanding

One aspect that the MHD theory has already been able to deal with is the global development of solar flares constituting an explosive release of magnetic energy from the Sun's corona. However, **J. Kuijpers** (University of Utrecht), in reviewing problems in understanding features of solar and stellar corona, thought that the difficulties mostly relate to plasma waves. For example, the trigger for a flare is unknown. He argued that that the global instability leading to flaring arose from a strongly enhanced resistivity in a small region owing to the presence of plasma waves that lead to the formation in the sheared corona of a topologically separated "gas blob".

### Wave-particle interactions in space — sources change

Plasma waves are also converted into radiation and it is radio data that has given impressive evidence for the non-stationary occurrence of four distinct types of plasma waves at various altitudes in solar and stellar corona. One candidate for efficient plasma radiation is linear instability at the harmonics of the electron frequency. **D. LeQuéau** (CPRE/CNET-CNRS, France) focussed on the physical phenomena underlying these cyclotronic wave-particle interactions (CPWI). Several examples highlighted the richness of the various processes which provide collisionless transfer of energy from an unstable gas species to the electromagnetic field, or to another species.

One can classify CPWI's according to the wavelength of the excited wave perpendicular to the direction of motion of the charged particle population (velocity $v$) taking part in the interaction. For $kv/\Omega << 1$ where $k$ is the wave number of the perpendicular waves and $\Omega$ is the cyclotron frequency, the electromagnetic field is felt as homogenous on the scale of the gyroradius of the particles (a particle always "sees" the same field). At the other extreme, a particle during its gyromotion feels a complex, multiharmonic, time dependent electromagnetic wave. LeQuéau concentrated on the former types of CPWI's as they are much easier to handle.

Consider one example of the latest developments in the field. So-called "superluminous CPWI" (when the phase velocity of the particles parallel to the direction of particle motion is $>c$, the velocity of light) is now thought to be the most promising candidate for explaining non-thermal radio emissions from the aurora surrounding magnetized planets such as the Earth. Recent measurements made aboard the VIKING satellite show that the sources of this radiation are inside thin accelerating regions in the aurora, and not below them as was believed for some time. This has led to a complete reappraisal of the free energy source at the origin of the emission. Explaining the difference between the old and new sources is not straightforward, save to say that the new source of superluminous CWPI is thought to originate in "quasi-trapped" electrons.

### Multipoint techniques — the future is here

The polar orbiting VIKING satellite also figured heavily in the discussion by **R. Boström** (Swedish Institute of Space Physics) of a dominant trend in astrophysics, namely multipoint measurement techniques to probe many sorts of wave phenomena in the Earth's magnetosphere. These studies may help us understand related phenomena in more distant parts of the Universe.

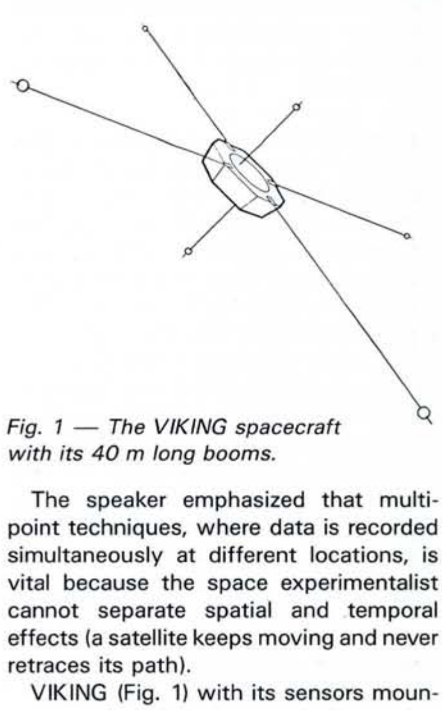

*Fig. 1 — The VIKING spacecraft with its 40 m long booms.*

The speaker emphasized that multipoint techniques, where data is recorded simultaneously at different locations, is vital because the space experimentalist cannot separate spatial and temporal effects (a satellite keeps moving and never retraces its path).

VIKING (Fig. 1) with its sensors mounted on 40 m long booms, is interesting because it is a prelude to what will emerge from a follow up mission IMPACT, the FREJA satellite in 1992 and ESA's remarkable CLUSTER project involving a group of well separated satellites due to be launched in 1995. It has, for example, permitted the first study of the Earth's magnetospheric waves using an interferometric technique where a field quantity is observed simultaneously at two different points. It provides information in one direction (parallel to the boom) of spectra as a function of the wavevector component for wavelengths approximately equal to the separation between the sensors. These spectra are much more useful than conventional power spectra.

One result of a correlation analysis in the frequency domain is a phase spectrum showing the phase relations between signals as a function of frequency. On rotating the boom, the phase difference is zero at all frequencies when the boom is aligned with the Earth's magnetic field. At 90°, the phase difference increases linearly to about 100 Hz before showing a more complex dependence at higher frequencies. This information is recorded as a function of time by having the satellite with its boom rotate through 360° every 20 seconds. The cover picture shows a representation of the output. The phase differences are colour coded white (−180°), intermediate (0°) and dark (+180°). One sees wavelengths shorter than the the probe separation showing up as 360° phase shifts (the intermediate scale wraps around) at frequencies above 75 Hz.

VIKING has found that these magnetically aligned spatial irregularities, corresponding to small scale regions of turbulence in the plasma density, are present everywhere in the magnetosphere up to 13500 km. When their origin is understood we shall be on the way to building a coherent picture of auroral phenomena.

### Interacting with plasma waves — something for everyone

J. Kuijpers mentioned another intriguing technique to probe naturally occurring plasma wave problems. It involves irradiating the solar corona with strong radio waves to detect low frequency emissions, that cannot escape the corona, by "up-converting" them to a frequency above the cut-off frequency. Space scientists using these interactive techniques, which have so far given inconclusive results, may learn some useful ideas from tokamak physicists who use interactive techniques to stabilize their laboratory plasmas.

**D.C. Robinson** (Culham Laboratory, UK) reviewed the wide variety of waves that are deployed to generate and heat magnetically confined fusion plasmas. Low frequency waves within the plasma were also discussed: those with frequencies of a few kHz result in turbulence that is important for transporting particles and energy. Those with a large amplitude, a global character and having frequencies close to the diamagnetic drift frequency can become unstable with potentially catastrophic results accompanying an abrupt pause in the plasma current. Controlling the latter represents a major trend in tokamak physics as they are the dominant instability problem in present and future magnetic confinement devices such as JET.

To illustrate the interactive techniques we shall consider the large amplitude, low frequency waves. The pre-distruption phase is characterized by a growing, oscillatory poloidal magnetic field (see Fig. 2) corresponding to perturbations at several resonant surfaces. They can be suppressed by fast feedback control using magnetic sensing coils with high frequency feedback applied *via* helical driving coils. By postponing or reducing disruptions tokamak performance has now been improved significantly.

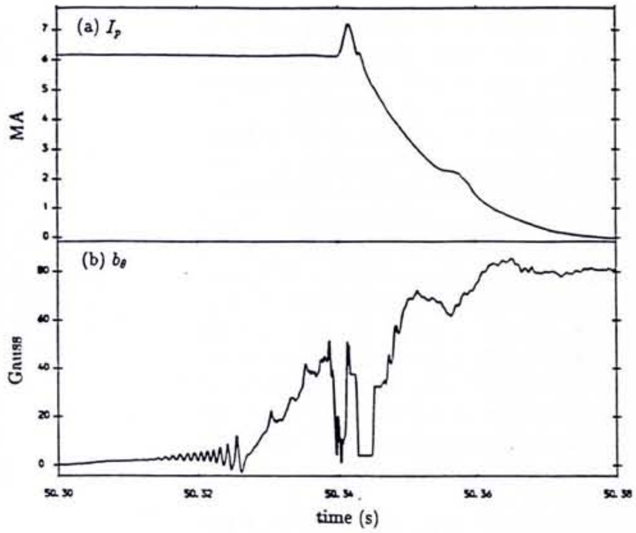


*Fig. 2 — Upper: abrupt termination of the plasma current ($I_p$) in the JET tokamak fusion reactor. Lower: a rapidly growing oscillation in the poloidal magnetic field strength ($b_\theta$) precedes the termination.*

One must also interact in a very strong manner with a tokamak fusion plasma to establish a steady toroidal plasma current so that the local circular magnetic field causes the total field lines to spiral about the toroidal axis, thereby preventing particles from drifting out of the plasma. The conventional approach uses pulsed magnetic induction to drive the plasma ring current as the secondary of a transformer. Steady state non-inductive current drive systems are being evaluated as they do not exploit an inherently unstable transient mechanism which may contribute to the instabilities discussed above.

**D.W. Faulconer** (Ecole Royale Militaire, Brussels) described the results of a theoretical analysis of the physical mechanisms underlying these current drives, which generally involve the toroidal injection of waves with or without particles. Each of the various alternatives had its advantages and disadvantages: some (lower hybrid wave and neutral beam injection) are efficient but unable to penetrate deep into the plasma, although new technology may solve the latter problem for neutral beam injection. Others (electron cyclotron resonance and fast wave methods) were predicted to show good penetration but little experimental data is available to allow an accurate evaluation. They may, however, be useful as an ancillary technique for tailoring the toroidal current.

# Microtechnology Revives Old Concepts

"Physics of Low Dimension Systems" (Session S 7)

Modern techniques allow one to fabricate structures with a low number of dimensions that can be used to examine systematically the physics of these systems. The invited talks in the session focussed on various electromagnetic properties which can be investigated by exploiting the trend: some of the posters described other features.

### High capacitance junctions — towards a new standard

A somewhat overlooked partner of the Josephson (magnetic) effect is its dual, the single electron tunnel (SET) effect first observed in granular films before Josephson junctions were predicted. Modern lithographic techniques now make it possible to fabricate reproducibly the very small junctions in which SET effects can be investigated in well defined configurations so the field has made some important advances recently. **P. Delsing** (Chalmers University of Technology, Göteborg) pointed out in his description of some new measurements of SET effects in manufactured junctions that if nature had not decided to make the fine structure constant larger than unity, the situation would have been different: SET junctions would have been easier to bias than Josephsons and historically work would have concentrated on the former.

But what is a SET junction? Physically, a metal electrode is evaporated on a silicon wafer which is lighly oxidized before depositing the second electrode. An microscopic junction is then formed using electron beam lithography. In a SET junction, the charging energy equals $Q^2/2\,C$ for a junction charge $Q$ and junction capacitance $C$. Electron tunnelling is virtually blocked if the potential energy $eV$ for a voltage $V$ is less than than the elementary charging energy $E_c = e^2/2\,C$. This is called the Coulomb blocade of tunnelling.

SET effects can be observed if the junction is so small that $E_c > k_BT$, the thermal fluctuation energy. For a 1 µm × 1 µm junction, the temperature $T$ must be $< e^2/2k_BC \approx 30$ mK illustrating the difficulty of realizing a practical device at an accessible temperature. Secondly, tunnelling must not be initiated by quantum fluctuations and this places a restriction on the resistance. Nevertheless, working devices have been produced, and Delsing described the first reliable measurements of the interaction of an electrically biased, one-dimensional array of single oxide layer SET junctions with microwaves.

For some junction, plots of the differential resistance versus the current for microwaves with different amplitudes and frequencies gave stable peaks (their magnitudes increased as the frequency increased but their positions remained fixed — see Fig. 3). On increasing the temperature to 100 mK the peaks became smeared; at 900 mK there were still some traces. Since this latter temperature corresponds to 25% of $E_c$, phase locking of the incident microwaves to SET oscillations is remarkably strong.

The speaker argued that only one type of oscillation could be responsible for the peaks, namely Bloch oscillations. If these oscillations can be made more pronounced, phase locking to the microwaves should result in horizontal steps on a current-voltage *(i-V)* curve analogous to classical Josephson effects. It may then be possible to realize a current standard equivalent to the the Josephson voltage standard and the quantum Hall effect resistance standard.

Using similar devices, but with different configurations, groups at Delft and Orsay have been able to obtain step-like *i-V* curves, the so-called Coulomb staircase. The difference here is that their arrays of junctions were driven by RF oscillations; they could not produce stable peaks with a DC driver. However, the work is a move in the right direction towards a current standard.

**Quantum dots — a test bed for theory**

Modern lithographic techniques also allow one to define confined regions that are ballistic (free of impurities) in the two-dimensional electron gas of a GaAs-AlGaAs semiconductor heterostructure. When the size of such a region approaches the Fermi wavelength, electron states are quantized and electron transport is quantum ballistic. **L. P. Kouwenhoven** (Delft University of Technology) described how a zero-dimensional state corresponding to splitting of the electron states between the device's two barriers can be magnetically induced. The discrete atomic states in such a "quantum dot" develop collective states, the bandstructure, on aligning several dots in a periodic array. The geometry of a working device is illustrated in Fig. 4. A voltage $V_{g1}$ on the first gate defines 16 fingers in the 2-d electron gas. Increasing the voltage $V_{g2}$ enlarges the depletion region around the first gate producing a periodic l-d potential. Measurements of the conductance at 10 mK in a 2 Tesla field show quantum Hall plateaus at certain $V_{g1}$ on changing $V_{g2}$ (Fig. 4) with large oscillations separated by small oscillations equal in number to the number

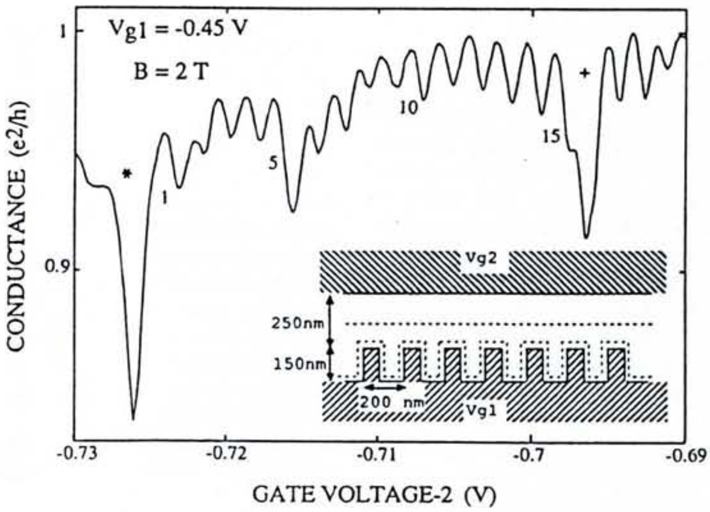


*Fig. 4 — Conductance as a function of the second gate voltage $V_{g2}$ with a fixed first gate voltage $V_{g1}$ for a one-dimensional array of quantum dots in a GaAs-AlGaAs heterostructure. Inset is shown a schematic illustration of the gate geometry and the depletion regions in the 2-d electron gas. The number of small oscillations marked 1..5..10..15 across the quantum Hall plateau equals the number of quantum dots.*

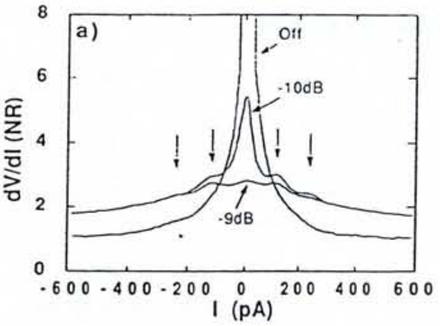


*Fig. 3 — Differential resistance of a SET array as a function of the driver current at different microwave radiation powers (50 mK; 0.75 GHz): first and second order stable current peaks are indicated with arrows.*

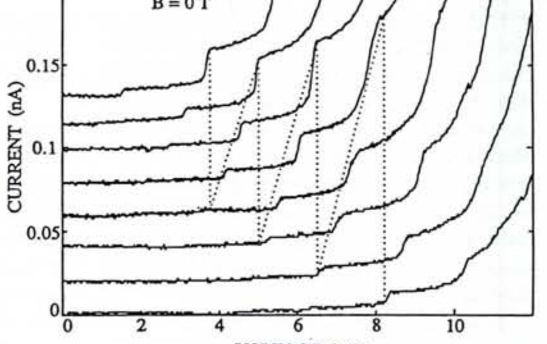


*Fig. 5 — i-V chart of the 1-d quantum dot array of Fig. 4 without a magnetic field showing Coulomb staircases. The curves for $V_{g2}$ varied by multiples of 1 mV are offset for clarity.*

of quantum dots. These oscillations correspond to the formation of discrete states in the bandstructure of the 1-d crystal device and the array is indeed behaving as a 1-d crystal.

An oscillating conductance owing to charging effects analogous to those described above for small capacitance tunnel junctions have also been observed in the weakly coupled array of quantum dots. The experiments here involved measuring the conductance on changing $V_{g2}$ at < 1 K without a magnetic field. Clear evidence for a Coulomb staircase arising from charging effects was detected (Fig. 5). Work is in progress to see if this quantum effect originates from all the dots, or from just one which acts as a bottleneck. Notwithstanding, we have here another example of the use of microdevices to study fundamental phenomena with important technological implications.

**Superlattices — modulators and emitters**

Another revival of established concepts deriving directly from modern techniques for fabricating sub-micron structures was discussed by **P. Voisin** (ENS, Paris). He showed that novel optoelectronic properties in semiconductor superlattices (sequences of very thin epitaxial layers of different semiconductors) displayed Wannier quantization. Up to now there has been no convincing evidence for this effect because the so-called $\eta$ parameter given by $eFd/\triangle$, where $F$ is the external electric field, $d$ is the lattice spacing and $\triangle$ is the band width, is very small ($< 10^{-2}$).

In the Wannier effect, field induced quantization arises where the energy spectrum of eigenstates in a crystal in the presence of an external field is a ladder of discrete energy levels. The corresponding wave functions are localized. With a small modification (energy levels are narrow resonances instead of bound states), the once controversial Wannier concept is now generally accepted.

Semiconductor superlattices can be considered as a stack of quantum wells (QW) separated by thin potential barriers so the QW eigenfunctions are delocalized and $D \approx 50$ Å, the superlattice spacing. Hence $\eta > 1$ and the Wannier effect should be observable. And so it is. For example, it arises in a InGaAs-AlGaInAs superlattice as a shift of the adsorption line to the red or the blue depending on the strength and polarity of the applied electric field (Fig. 6). Other so-called "excitonic" features also develop.

A natural next step was to apply both electric and magnetic fields normal to the superlattice planes: the adsorption features become sharper and sharper as both fields increased owing to Wannier quantization of axial motion combined with Landau quantization of in-plane motion.

The novel optoelectronic effects of Wannier quantization will find technological application as modulators, *etc.* Meanwhile, the hunt is on for other interesting effects such as interband radiative transitions between the Wannier levels to produce FIR emitters. This particular search has failed so far but others are anticipted to be successful, especially as theoretical understanding of superlattice electronic structures improves.

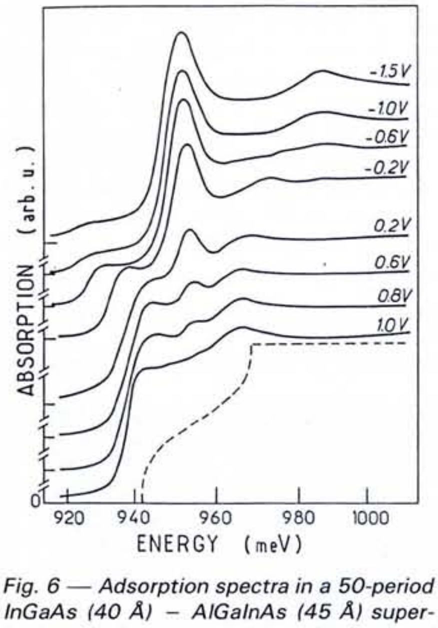


*Fig. 6 — Adsorption spectra in a 50-period InGaAs (40 Å) – AlGaInAs (45 Å) superlattice: the lower trace shows the flat-band spectrum with a steep adsorption edge followed by a broad shoulder and an adsorption plateau. When the electric field strength is decreased from the value giving flat bands a vertical transition appears.*

# From The Unsupported To The Supported

"Clusters of Atoms and Molecules": (Session S 4)

Confining a metal in a small volume gives different chemical and physical properties to the bulk so small clusters are of interest in both basic and applied science. Recent experimental breakthroughs mean that it is now possible to study the properties of unsupported clusters and the structures of supported ones. The current trend is to link these studies using, for instance, structural simulations and computer modelling. Interesting links with other fields, *e.g.* nuclear physics, are also developing.

**Electronic structures — links to nuclei**

Studies in thin film and submicron electronic devices, as discussed above, show that confinement of charge carriers to small volumes induces discrete energy levels. The order and spacing of the levels depend on the geometry of the confined volume as well as on details of the effective potential seen by the electrons. These quantum size effects are well know in nuclear physics and they are expect to show up in the transition region from single atoms to the bulk.

Photoelectron spectroscopy has recently been exploited to map directly the electronic band structure in clusters of different sizes. In the technique described by **K.-H. Meiwes-Broer** (University of Bielefeld, FRG), cold cluster ions are produced by laser vaporization or using a special pulsed arc source. The emerging jets enter a two-stage accelerator to determine the charge states. The clusters are then struck with a laser pulse at the starting area of a time-of-flight electron spectrometer. Because the ion cluster beam intensity is low it is has been necessary to design special spectrometers with a high acceptance angle.

Photoelectron spectra (Fig. 7) for sequences of clusters of increasing size show that the evolution of the electronic structure occurs in steps (each ion cluster

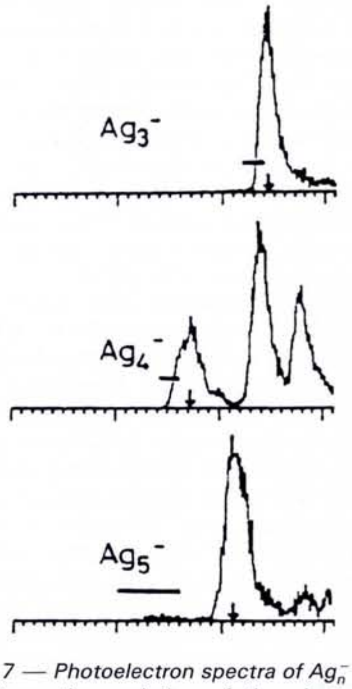


*Fig. 7 — Photoelectron spectra of $Ag_n^-$ ion clusters: the evolution of the electronic structure with increasing cluster size takes place in steps (vertical axis — photoelectron intensity; horizontal axis — electron binding energy in eV).*

size has its own "fingerprint"). The spectra are rich in detail so only one or two aspects can be illustrated. An interesting trend was the observation of steps in the electron affinities at progressively larger numbers of atoms, $n$, in the cluster. According to a simple jellium model (*i.e.* assuming a uniformly positively charged background) these steps arise because whenever a shell of delocalized electrons is closed and a spherical, highly stable configuration reached, addition of one electron yields a low ionization energy since a new shell is being filled. Gaps in electron affinities therefore arise in $Ag_n^-$ ion clusters at $n = 8, 20$, *etc.* In the jellium model, the low energy lines correspond to deviations from spherical symmetry and the observed electron affinities agree with those calculated for the model. The gaps also correspond to changes in other properties (*e.g.* chemical).

A second feature is that the electronic band structure for a cluster is totally different to that of bulk metal. The simple theory predicts a $1/r$ behaviour for photodetachment energies and this has been observed: ionization potentials and electron affinities for Ag and Cu ion clusters extrapolate to the the work function of the bulk metal. The jellium model is thus able to predict ground-state properties of clusters.

**C. Bréchignac** (CNRS Orsay ) following along similar lines described the unusual properties of alkali metal clusters arising from the delocalization of valence bands. For this she used photothermodesorption to probe the stability and response to excitation of these clusters. A cluster beam was ionized with a laser pulse, mass selected and the time-of-flight measured. For Na clusters, it was found that as the cluster size increased the ratio of monomers to dimers varied periodically and at large $n$ approached the value for the bulk. The one-electron shell model was able to predict the observed evaporation rates and dissociation energies of the clusters. Essentially, clusters with an even number of electrons were more stable.

Collective excitations were studied in a second series of experiments by photodissociating the ionized, mass selected cluster ions and then determining the time of flight. Collective excitation of the cluster's electron gas gave some intriguing effects. One bore a strong analogy to well known results in nuclear physics. It was found that non-spherical $Na_{11}^+$ clusters exhibited different polarizabilities along different axes. The equivalent in nuclear physics is the ejection of a neutron (instead of an atom) using $\gamma$ photoexcitation of a nucleus. In this case, nuclei that do not have closed shells also gave different polarizabilities along $c$ and $a$ axes. In contrast to nuclei however, nonspherical clusters can be examined up to large sizes where giant resonances should exist. The quantum size effects found in nuclear physics are therefore, as expected, being found in clusters and this should herald some fruitful multidisciplinarity in the years to come.

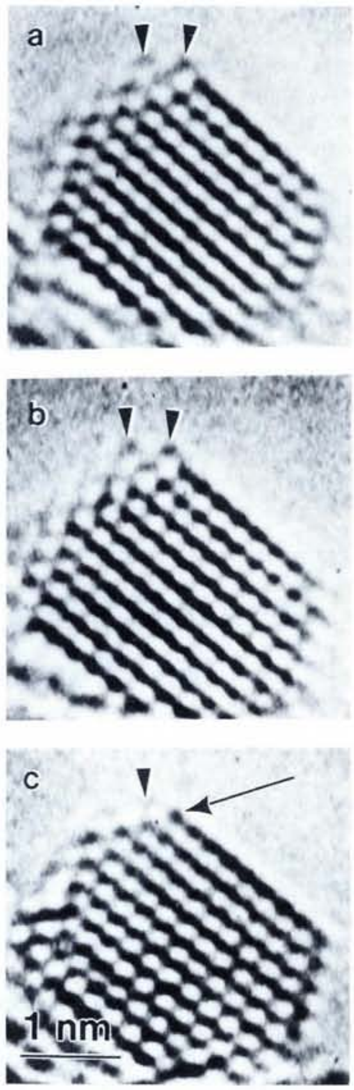


*Fig. 8 — High resolution electron microscopy of the growth of a {100} surface layer on a ccp Au cluster. A somewhat ordered "cloud" of atoms appears in (a) and (b) prior to the ordering of the new surface marked with the long arrow.*

**HREM studies — melting or growing?**

At the individual, microscopic level, atoms in small supported clusters can be imaged in high resolution electron microscopes (HREM) and **J.-O. Bovin** (National Centre for HREM, Sweden) described a similar richness in the structures observed. Small clusters undergo rapid, temperature dependent structural rearrangements, the speed increasing as the size and contact area with the support decrease. A impressive demonstration is a change from five to three to two-fold symmetries observed in a 400 atom Au cluster as it rotates on a carbon support.

Diffuse, varying contrast extending 10 Å out from clusters surfaces has also been found. The nature of these "clouds" is not fully understood but one possibilty is partial surface melting suggested by molecular dynamics simulations (see below). The latest work shows, however, that prior to a column of atoms being added to the surface, diffuse fluctuating contrast is seen (Fig. 8). This result suggests that the clouds arise from an initial state of growth: atoms approaching the surface jump around looking for a sufficient number of stable bonds and the formation of a well-ordered column on the surface. Some interesting ordering reaction may then take place in the column after the "cloudy pre-growth" stage.

**Computer simulations — linking properties and structure?**

**W. Andreoni** described how computer simulations play a vital complementary rôle to experimental studies of the properties of unsupported clusters. The *ab-initio* Car-Parrinello method as well as classical molecular dynamics have been applied successfully to microclusters. Topics investigated include equilibrium geometry, electronic properties and vibrational spectra. Of particular interest is the melting question in the light of the previous speaker's observations.

## 1990 Hewlett-Packard Europhysics Prizewinners

**R. Car** (on left) and **M. Parrinello** (right) of the International School for Advanced Studies, Trieste were handed their 1990 Hewlett-Packard Europhysics Prize by the President, R.A. Ricci, at EPS-8. They developed a powerful method for the *ab initio* calculation of molecular dynamics which can be used in the simulations of clusters.