reflection of broadband light from the microcavity. The reflected light spectrum depends on the strength of the coupling. A weakly coupled system exhibits only one reflection resonance — a pronounced dip in the spectrum (at 113 meV in Günter and colleagues’ system). Strong and ultrastrong coupling, meanwhile, result in two reflection resonances that are clearly separated from each other by up to 20% of the original resonance’s energy, and that are located on either side of this resonance (see Fig. 3 of the paper on page 180).

But let’s restate the question: how fast can strong light–matter coupling be turned on or off? To address this question, the authors’ used a high-energy light pulse of 12-femtosecond duration that could excite electrons from the valence band into the lowest-energy sub-band within that timescale. They found that the strongly coupled light–matter system switches on almost instantly, not at its own intrinsic speed (the oscillation of its light field) but at the speed of the light pulse used to pump the electrons (12 femtoseconds compared with 37 femtoseconds): as soon as the electrons reach the conduction sub-bands, the light–matter coupling is established. What’s more, the switch is done non-adiabatically rather than adiabatically — that is, the system’s coupled quantum state does not emerge gradually but rather switches on abruptly.

Günter and colleagues’ work is excellent news in many ways. First, the observation that light–matter coupling can be tuned in less than one cycle of light means that a number of non-adiabatic, non-thermal-equilibrium light–matter phenomena, which belonged solely to the niche of theory, can now be tested in experiments. For example, the observation of the emission of virtual photons lodged in every optical cavity should now be possible. Second, the fact that the experiments are conducted at ambient temperature and pressure makes them accessible to a wider group of experimentalists. Finally, the authors’ demonstration of ultrafast switching of ultrastrong light–matter coupling in semiconductor-based structures may, in the long run, prove very useful for communication applications.

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**CONDENSED-MATTER PHYSICS**

Pressure for change in metals

N. W. Ashcroft

When is a metal not a metal? When it is under high pressure, if it’s lithium or sodium. The strange behaviour of dense forms of these elements exposes difficulties with commonly used models of electronic structure.

The physical laws that govern the behaviour of individual particles of matter can be relatively simple compared with the difficulties of understanding systems that contain large numbers of them. Yet such difficulties must be overcome if one is to understand the subtle quantum physics of the condensed states of matter. So-called simple metals, such as lithium and sodium, have had a pivotal role in studies of metallic solids, because their electronic behaviour is plausibly described using an approximation known as the nearly-free electron model. But two reports in this issue reveal that lithium and sodium do something quite remarkable under pressure that can’t readily be explained by this approximation — they adopt semiconductor-like forms.

Some 75 years ago, two classic papers were published describing the “constitution of metallic sodium”. These papers revealed that, under ordinary conditions of temperature and pressure, the electronic structure of sodium is quintessentially free-electron-like. In other words, the behaviour of its valence electrons (the outermost electrons responsible for carrying an electric current) is similar to that of a dense gas of otherwise free electrons. The only differences in behaviour are relatively minor perturbations caused by weak interactions of the valence electrons with the positively charged core structures of their atoms (that is, the ions formed when the valence electrons leave the atoms). Nearly-free electron behaviour was soon recognized as being characteristic of many metals, but especially of lighter elements classified as simple metals. The ‘simplicity’ of these metals also refers to the spatial arrangements of the crystal lattices formed by the atoms. For example, under ordinary conditions, lithium and sodium often adopt one of the most straightforward of all crystal structures — the body-centred cubic arrangement, consisting of subunits in which eight atoms form the corners of a cube while another sits at the centre of the cube.

But it is increasingly evident that the electronic structure of simple metals under high pressures — and therefore at higher densities of the metals — can be a far cry from those observed under ambient conditions. In the case of lithium, Matsuoka and Shimizu (page 186) demonstrate that, at pressures of about 80 gigapascals (just a little under a quarter that at the centre of the Earth, or roughly 800,000 times atmospheric pressure), the electrical resistance of the element increases abruptly to more than 10,000 times its value at atmospheric pressure. The temperature dependence of the resulting material is then much more characteristic of a semiconductor than of a metal.

Meanwhile, Ma et al. (page 182) report that thin slices of sodium (about 3–5 micrometres thick) become transparent to visible light at pressures of about 200 gigapascals (just over half the pressure at the centre of the Earth) in a high-pressure cell. This suggests that the metal has become an insulator, or at least a semiconductor. The authors also obtained spectroscopic data from their dense sodium, which can provide clues on what transformations might have occurred in the crystal structure. These results and those of Matsuoka and Shimizu are surprising, because they cannot be easily explained by historical assumptions about how the crystal structures of simple metals might change under pressure. In particular, there are no special reasons to expect dramatic changes in the conductivities of these metals with increasing pressure, even if the crystal structure undergoes moderate changes as a result of this treatment.

So might these findings presage a shift in viewpoint about the electronic structures of high-density metals? Up to now, it has been generally accepted that electrons form patterns of varying electron density around the core structures of their atoms, in response to the electric fields generated by these core structures. Indeed, this long-standing notion — which results in atoms having almost spherical shapes — evolved into the concept of electron shells and subshells in atoms.

But what happens if the average separation of atoms in a solid is significantly reduced (say, by 40%) from the value at ordinary pressure? Under these circumstances, each atom suffers invasion of its territory by its neighbours, which can affect the shapes of the local volumes available to electrons. Furthermore, the core structures of the atoms are forced to overlap; valence electrons, which are already largely excluded from the ion cores, are thus separated even further. To accommodate this increasing exclusion, the valence electrons could instead occupy interstitial locations between the cores, and the crystal structure of the metal might well have to change to accommodate such electron-occupied interstices. Recent extraordinary revelations about the complexity of the structure of sodium at high densities arguably provide ample testimony to the likelihood of such pressure-induced changes.
In the current reports\(^1,2\), the crystal structures at the onsets of the non-metallic states of lithium and sodium have not been definitively established. Ma \textit{et al.}\(^3\), however, used extensive quantum-mechanical calculations and structural-refinement techniques to predict that sodium adopts an unusual “distorted double-hexagonal close-packed” structure (see Fig. 4a on page 184) at high pressures. This structure is in fact shown to be an insulator at low temperatures. Nevertheless, one cannot yet say with certainty that dense sodium takes this form, because the calculations predict structures at a temperature of absolute zero, whereas Ma and colleagues’ measurements were made at room temperature. The calculations also assume that the core structures are infinitely massive. In fact, both lithium and sodium are light elements, and so quantum effects of the atoms associated with their lattice dynamics might well be important for determining the actual structures adopted by the dense metals.

The results\(^1,2\) are not entirely unheralded, as significant changes in the optical characteristics and conductivity of sodium\(^4\) and lithium\(^5\) have previously been noted at pressures not too far from those now described. Nor are the results without some theoretical precedent: about ten years ago it was predicted\(^6\) that lithium might well depart from its simple crystal and electronic structures at higher pressures without some theoretical precedent: about ten years ago it was predicted\(^6\) that lithium might well depart from its simple crystal and electronic structures at higher densities. And predictions for sodium soon followed suit\(^7\). But what the present results most assuredly demonstrate is the importance of pressure in revealing the limitations of previously hallowed models of solids and their associated electronic behaviour. Furthermore, it is clear that the structures adopted by solids (and even liquids) under pressure will provide stringent tests\(^8\) of our ability to predict both the forms and thermodynamic behaviour of condensed states of matter.

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### CELL BIOLOGY

**Detached membrane bending**

Hélène Barelli and Bruno Antonny

*Cells use various protein complexes to remodel membrane-bound organelles. In vitro reconstitution of the activity of one such complex, ESCRT-III, shows that it promotes membrane bending in an unconventional way.*

Many transmembrane proteins — including those that span the cell membrane — are degraded within cellular organelles called lysosomes once their work is done. Reaching the lysosomes is not simple, however, and involves several membrane-vesicle trafficking steps\(^9\). On page 172 of this issue, Wollert \textit{et al.}\(^9\) elucidate the role of the components of the ESCRT-III protein complex in one stage of this process. The authors’ results are of interest not just for the insights they provide into the processes of intracellular trafficking and protein degradation, but also because ESCRT proteins mediate the budding of certain viruses, including HIV-1, as well as the separation of the two daughter cells at the end of cell division.

So what is the itinerary for the journey of a cell-membrane protein to the lysosomes? First, small portions of cell membrane invaginate and become detached to form organelles called endosomes, incorporating the proteins. The endosome further invaginates internally into its own lumen to form several intraluminal vesicles (ILVs). Endosomes with their ILVs are called multivesicular bodies, and eventually fuse with lysosomes, where ILVs and their contents are degraded by the cocktail of lysosomal enzymes.

Compared with other membrane-deformation events that occur in the cell, ILV formation is puzzling (Fig. 1). Vesicles generally bud from organelles (such as the Golgi complex) in the opposite direction to ILV formation: a protein coat assembles on the cytoplasmic side of the organelle membrane to form an outer shell and impose deformation towards the cytoplasm\(^10\). Once the vesicle has become detached from the membrane, the protein coat disassembles and is reused for another round of budding.

Given the opposite topology of ILVs, budding away from the cytoplasm, could it be that ESCRT-III sculpts the membrane from inside the bud? After all, induction of curvature from the inside has precedents: some proteins with

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**50 YEARS AGO**

A Congress was held in Singapore during December 2–9 to celebrate “the Centenary of the formulation of the theory of Evolution” by Charles Darwin and Alfred Russel Wallace and the bicentenary of the publication of the tenth edition of the ‘Systema Naturae’ by Linnaeus\(^11\). It was particularly fitting that this Congress should have been held in Singapore for … it directed special attention to the work of Wallace, who was one of the greatest biologists ever to have worked in south-east Asia … Prof. Haldane then delivered his presidential address … The president emphasised the stimuli gained by Linnaeus, Darwin and Wallace through working in peripheral areas where lack of knowledge was a challenge. He suggested that the next major biological advance may well come for similar reasons from peripheral places such as Singapore, or Calcutta, where this challenge still remains and where the lack of complex scientific apparatus drives biologists into different and long-neglected fields of research. From Nature 14 March 1959.

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**100 YEARS AGO**

On Monday evening Dr. M. A. Stein read before the Royal Geographical Society a paper on his geographical and archaeological explorations in Chinese Turkestan in 1906–8 … He was greatly desirous of examining a secret store of ancient manuscripts which had been accidentally discovered by a Taoist priest in the Caves of the Thousand Buddhas ... These were piled up without any sort of order to a height of 10 feet, and comprised not only written documents, but fine paintings on silk and cotton, ex-votos in all kinds of silk and brocade, and streamers in various fabrics. Dated documents showed that the chamber must have been walled up about 1000 a.d., but some of the records dated back so far as the third century a.d. From Nature 11 March 1909.