The quest for pure electron lattices

SIR — The very interesting work on observing three-dimensional electron lattices, reported in News and Views[1], is even more widely relevant than discussed in the brief space available. We note here other laboratory experiments and also, perhaps surprisingly, some astrophysical theory. An essential point of departure stems from the (correct) observation in the article that it is "taken for granted that an electron lattice can form only if embedded in a neutralizing sea of positive electric charge". An electron lattice can be formed *without* such a neutralizing background.

It has been known for years that a magnetized Penning trap can stably store single charged particles for extremely long periods. Such a trap consists simply of an axially symmetric electric quadrupole (two negative electrodes with a positive ring electrode in between, preferably with hyperbolic cross-sections of the appropriate curvature) and a magnetic field along the symmetry axis. The magnetic field prevents a charged particle from escaping across the magnetic field and the quadrupole electric field confines the particle (if negatively charged for the above charging of the electrodes) along the axis. Until fairly recently, it was not understood what happens if one fills such a trap with a large number of particles. Older literature vaguely discussed 'clouds' of trapped particles. It is now known that the charged particles condense effectively to form what appears very much to be a liquid. That is to say that the particles are confined to a spheroidal volume of constant density with a sharp interface to the surrounding vacuum. These sharp discontinuous surfaces were predicted theroretically for both the laboratory and astrophysical cases[2,3]. The surface thickness separating the plasma from the vacuum is shown to be only of the order of the Debye length, which is small compared with the system scale in the neutron star case even for million-degree plasmas, and in the laboratory case for the relatively cool plasmas that can be produced there (room temperature or less). Moreover, such systems ('non-neutral plasma' is the usual term in laboratory circles) have been created in the laboratory with both electrons[4] and ions[5]. Indeed, in the case of the ions, the particles have been cooled to a temperature (0.1 degrees kelvin) where the system should not only appear liquid-like (confinement to a variable shape volume of constant density) but actually be a liquid in the sense of large particle–particle correlations. Future experiments aspire to produce a trapped solid of ions (D.J. Wineland, personal communication). The workers at the University of California at San Diego have trapped the electrons in a similar configuration, using ring electrodes at the ends of a long solenoid that parallels the magnetic field axis. It may be feasible to cool such trapped electrons to temperatures where they are liquidized or solidify[6]. In either case, the formation of an ideal 'theoretician's' lattice of totally non-neutral plasma free of interfering background neutralizing charges seems within reach.

In the case of astrophysics, solidified states of matter have been expected for neutron star interiors (for example, refs 7,8). However, it now seems increasingly possible that the exteriors of magnetized neutron stars may, in many cases, be surrounded by such quasi-liquid non-neutral plasmas pulled from their surfaces. The essential ideas were forwarded by a number of people such as Holloway[9] who pointed out the likelihood of vacuum–plasma interfaces, Rylov[10] who first speculated on how such plasmas might be distributed about pulsars, and Jackson[11] who also argued for condensation of such plasmas about neutron stars. The laboratory effort itself goes back at least to Trivelpiece[12], and an entire book has been written on the properties of nonneutral plasmas[13].

Not only do these remarkable plasma experiments open up the possibility of creating pure liquid and solid plasmas, but they also underscore an interesting convergence in research on solid-state physics[14], with laboratory experiments on non-neutral plasmas and, surprisingly, some astrophysical theory as well.

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Selfish DNA and the origin of introns

SIR — The selfish DNA or transposon theory of the origin of introns[1-9] is dismissed far too readily by Cornish-Bowden[10]. As introns are very often not at domain boundaries[11,12], the hypothesis of evolutionary exon shuffling to recombine protein domains is hardly the "most plausible suggestion" for their "function". It does not adequately explain either the origin or the evolutionary maintenance of RNA splicing. Although fusion of two genes by recombination between existing introns probably has been evolutionarily important, it does not explain the origin of the introns "in the first place". *De novo* intron formation by fusing two genes lacking introns is far more complex than fusion to produce an unsplit gene; it could hardly have occurred in a single step in an organism previously lacking RNA splicing[7]. Split genes and RNA splicing could not have evolved merely because they might millions of years later help a new protein evolve: evolution lacks such foresight[2].

The transposon hypothesis can explain the origin of introns and also of RNA splicing itself[3-7]. The presence of introns in mitochondria and chloroplasts, in particular, is best explained by transposition from the nucleus[5-7]. The different positions of the introns of the chloroplast *psbA* genes of *Chlamydomonas*[13] and *Euglena*[14], coupled with their absence from the ancestral cyanobacteria[13], supports insertional origin for chloroplast introns, rather than one from primordial gene fusions that created the *psbA* gene. The coding of proteins involved in splicing by certain introns in fungal mitochondria[4], and in a chloroplast gene[15], supports the thesis that such introns originated as defective transposons in which the RNA-splicing enzymes evolved from pre-existing DNA splicing enzymes specific for their termini[3-5].

This also can explain the origin of introns in general [3,4,7]. Suppose a transposon capable of precise excision inserted into a cellular gene, thus inactivating its transcript[4]. This first 'intron' would be exactly pliced out of the RNA if the DNA excisionase of the transposon mutated so as to be able to cut RNA instead of DNA, but retained its specificity for the sequence at either end of the transposon; this would simultaneously prevent its self-transposition and rescue the cell from its harmful insertion mutation.

This mutation would protect the cell from insertion mutations by any transposons generating similar terminal sequences upon insertion, and therefore have allowed the rapid intragenomic spread of kindred non-defective transposons; moreover these would have provided DNA excisionase activity allowing the rapid intragenomic spread of the defective RNA-splicing transposon itself[7]. So many genes would quickly acquire introns that RNA splicing could never be lost[1,2]. All descendants of this cell would be permanently infected with useless introns. RNA splicing could later acquire real functions for at least some genes, such as differential splicing to make different proteins from the same transcriptional unit[16]. This rescue hypothesis[4] provides an immediate and powerful mode of spreading for introns and RNA splicing. At one and the same time it involves intragenomic kin selection favouring the spread of selfish DNA, and conventional selection at the cellular level for protection from the harmful effects of certain selfish transposons. Alternatively, RNA splicing might have originated in a virus[7] before being taken over by the cell.