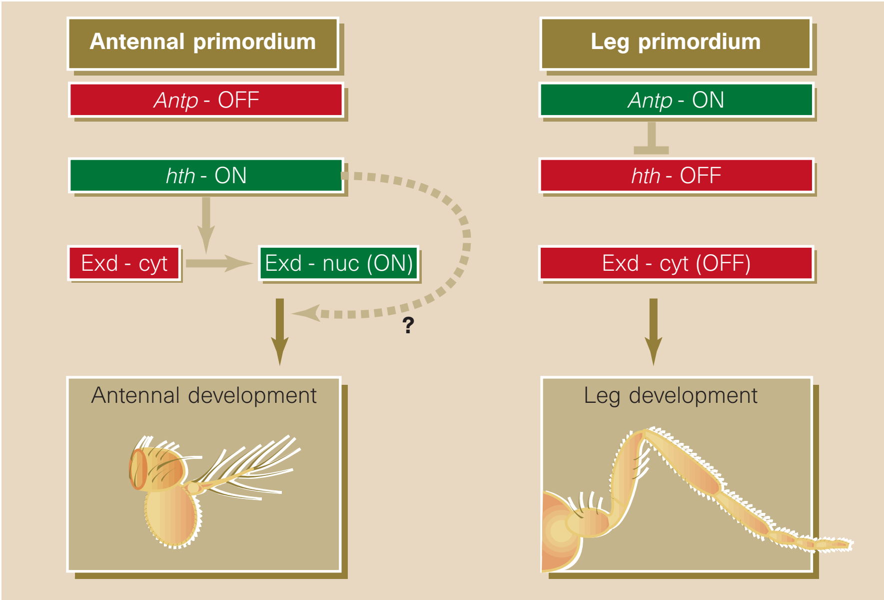

Figure 2 **Interactions between *Antennapedia* (*Antp*), *homothorax* (*hth*) and *extradenticle* (*exd*) that determine the development of the antennal and leg primordia. Gene activity is marked in green and lack of activity in red.** a, **In the antennal primordium, *hth* translocates the Exd protein from the cytoplasm (cyt) to the nucleus (nuc), and antennal development follows. The dotted line with the question mark indicates the possibility that *hth* might have a direct role not mediated by *exd*, as proposed by Casares and Mann[1].** b, **In the leg primordium the activity of *Antp* prevents transcription of *hth*, so Exd remains inactive in the cytoplasm and leg development ensues. Any mechanism that inactivates *hth* or prevents translocation of Exd (such as the presence of Antp protein in *Antp* dominant mutants) would transform the antenna into a leg.**

the normal context indicates it acts as a master gene for the antenna. In the antennal disc (as in the analia) there are no active Hox genes to interact with, so the antennal expression of *hth* probably reflects a function that is independent of Exd/Hox interactions.

Now consider again the transformation to leg that is produced by *hth* or *exd* mutant cells in the antenna. This is the same phenotype as seen with dominant *Antp* mutants, but Casares and Mann show that, unlike in the *Antp* mutants, this leg develops without activity of *Antp*, *Scr* or *Ubx*. It follows that a leg can be generated without Hox activity, suggesting that the leg pathway is the ground state for ventral appendages. Thus the ground pattern for both larvae and adults is thoracic, removing one of the worries mentioned above. Nor does *Antp* 'select' for a specific leg pathway — it simply represses *hth* in the leg primordia, thereby blocking antennal development and allowing the development of legs by default (Fig. 2). This supports Struhl's model[3] that *Antp* promotes a ground (mesothoracic) pattern by repressing cephalic genes. This basal pattern is modified towards prothoracic (first leg) by *Scr* or metathoracic (third leg) by *Ubx* in their respective primordia.

The downregulation of *hth* by *Antp* explains the phenotype of the dominant *Antp* mutants as being due to *hth* repression. It also explains the ability of other Hox genes such as *Ubx*, *abd-A*, *Abd-B* and even the mouse *Hoxd-10* to induce the transformation of antennae into legs[14,15]. These genes prevent the nuclear translocation of Exd[14] (most likely through *hth* repression), so the antennal to leg transformations are probably nonspecific and caused by a property that is common to Antp and other Hox proteins.

During embryogenesis, in contrast with leg development, *Antp* selects for a specific developmental pathway. Loss-of-function mutations[6,8] and experiments to induce ectopic expression[16] show that *Antp* determines the larval mesothoracic pattern — a function that is clearly distinct from the other Hox genes[8]. Why legs should be different is not clear, but different Hox genes have similar effects on appendages[15], possibly because these appendages have no *hth* activity, without which the Hox genes lack specificity. □

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Condensed-matter physics

The noise is the signal

Rolf Landauer

Noise is not only a hindrance to signal detection. Advances in measurement techniques mean that it can now be used to probe the kinetics of electrons. That is because interactions between electrons can regulate their relative motion, and so reduce noise. These interactions include not only the Coulomb repulsion, but also the Pauli exclusion principle, which prevents two electrons from behaving alike. Several new noise measurements[1–4] in different systems have produced insights into how these interactions affect electronic behaviour.

Eighty years ago, Schottky described the irregular 'patter' of electrons that cross a vacuum diode independently of one another, and called it shot noise. The mean-squared shot-noise current in a frequency range Δf is given by $2eI\Delta f$, where e is the charge on the electron, and I is the current. Some 20 years after Schottky, the case was described in which enough electrons are emitted from the cathode to repel each other and thereby regulate and reduce the fluctuations.

The new investigations[1–4] were prompted by precise measurements of noise at quantum point contacts. These are narrow passages of controllable width whose conductance tends to be quantized[5] in multiples of $e^2/\pi h$. Experiments[6] at CEA Saclay found that the noise corresponds with what is predicted by the simplest existing models of electrons that move independently (except for the effects of the Pauli exclusion principle). This lack of evidence for interactions is not surprising, as the group's two-dimensional semiconductor structure does not have many electrons in the region that matters, so Coulomb interactions are small. But a Yale group[1] has made high-frequency noise measurements on a thin, short, narrow, gold strip with a high electron density, and again the theory that allows only for the Pauli principle accounts remarkably well for the results.

Theorists expect interactions to yield

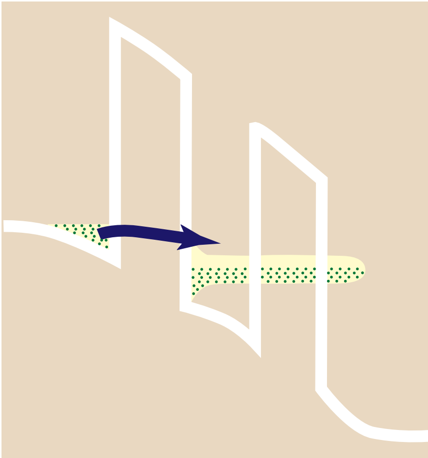

Figure 1 **Noise with feedback. Two potential barriers contain a bound state, whose energy overlaps that of electrons tunnelling into the well from the left. The shot noise is increased by positive feedback: excess electrons tunnelling in from the left raise the potential energy of the well, and so increase the overlap and allow still more tunnelling.**

more complex beasts, but in practice they must be sought in more exotic country. In the fractional quantum Hall effect, for example, theory predicts the existence of pseudoparticles, collective electronic states with fractional electric charge. Indeed, two experiments[7,8] have now seen shot noise reduced from what would be expected if the carriers had the same charge as independently moving electrons, demonstrating the presence of carriers with an effective charge of *e*/3.

Noise increases have also been observed, caused by Coulomb interactions. A group from Pisa[3] measured shot noise in current flow through two successive tunnelling barriers (Fig. 1). A bound state between the two barriers has an energy width that overlaps with the conduction band. If a fluctuation allows more electrons to enter the trap, the energy of trapped electrons rises, increasing the overlap and allowing more tunnelling. The shot noise is strongly increased by this positive feedback. This is the equivalent of the well-known critical fluctuations in thermal equilibrium, which appear as a state approaches instability. In this circuit the capacitance between the region containing the bound state and the two electrodes is shunted by the differential conductance of the two barriers in parallel. Instability of the voltage division between the two barriers arises when that net conductance becomes negative. Thus, the instability turns up when the magnitude of the negative differential conductance of the left barrier approaches that of the positive conductance of the right barrier. Such critical fluctuations in circuits were predicted decades ago[9].

The Pauli principle alone can suppress noise, as the quantum-point-contact experiments[6] demonstrated. Another demonstration of this comes from a Stanford group[2], who created the electronic equivalent of a half-silvered mirror (Fig. 2) by adjusting the height of a barrier that can transmit or reflect electrons. When the incident stream has all possible electronic states filled, it is regular and noiseless. The emerging streams are only half-filled with irregularly occupied wave-packet states, and so are noisy, as predicted[10]. When another fully occupied stream of incident electrons is added, now supplying enough electrons to fill all outgoing states, the noise in the emerging streams is greatly reduced.

As illustrated in Fig. 2, the Pauli principle allots at most one electron to each successive wave packet, and this can regulate the flow and reduce noise. Consider a conductor that is short enough to scatter traversing electrons in a coherent quantum-mechanical way, but long enough to transmit only a small proportion of the incident carriers, with most scattered back to the incident interface. At the output end we might expect few of the possible emerging electronic states to be occupied, and therefore to see little of the exclusion-principle noise reduction. This turns out to be wrong. Interference makes electron transmission through the sample highly non-uniform, like a laser speckle pattern, and this allows the Pauli principle to be effective, yielding a noise that is 1/3 of the classical shot noise[11].

This factor of 1/3 applies in a wider range of circumstances, including the case where electrons are scattered incoherently, but elastically. I have claimed[12] that this occurrence of 1/3 in the two cases is just a numerical coincidence; that there is no common physical mechanism. Remarkably, now, the same factor has turned up in another, very different, context[4]. A computer simulation shows that it also emerges where there are too few electrons for the Pauli principle to matter, but where the current-carrying electrons make an additional charge injected into a previously neutral material, they are scattered elastically and there is strong Coulomb repulsion between them. But the supposed universality of 1/3 is spoiled somewhat by the fact that a two-dimensional velocity distribution in this case would instead yield a noise reduction by a factor of two. So totally different physical processes can lead to the same factor-of-three reduction.

Noise measurements are only just emerging as a useful quantitative probe of electron kinetics, and many questions remain. A particularly intriguing proposal[13] concerns two unconnected conducting paths: the paths overlap at two separate places in space, but electrons from one path cannot cross into the other path. A magnetic flux in the space enclosed between the two points of overlap will have no effect on the current flow in either path, yet it should affect the correlation in noise between the two paths. □

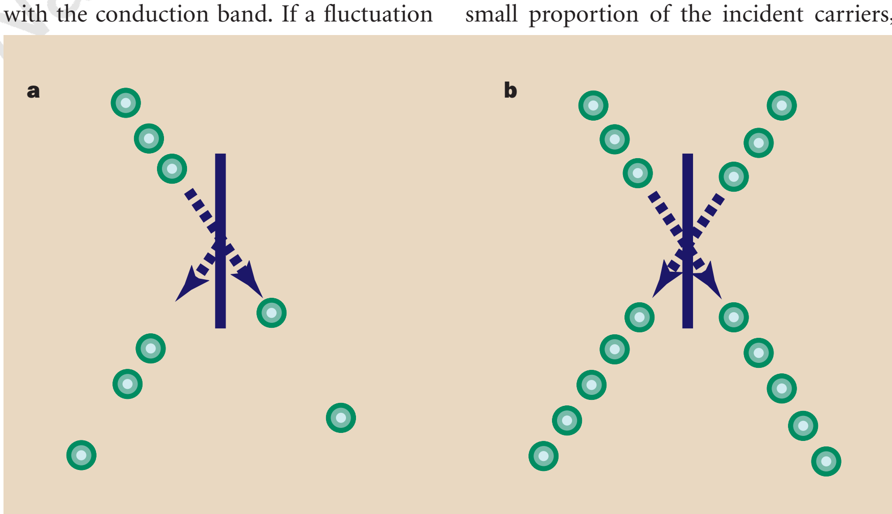

Figure 2 **Tightly packed electrons.** a, **A stream of electrons is split into equal parts at the barrier. All the possible incident states are filled with an electron, yielding a regular stream. The emerging half-filled streams are more random, and therefore noisy.** b, **When another stream of incident electrons is added, both emerging streams are full, and less noisy.**

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