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NOISE

Humpty Dumpty to Moslem art

W. Schleich and P.V.E. McClintock

HIGH-PRECISION measurements of gravitational-wave-induced length changes in Michelson interferometers, quantum-optical realizations of the Einstein–Bohr dialogue on Young's double-slit experiment using micromasers, bistable systems, hydrodynamical pattern formation and magically complex phase-space webs with the beauty of Moslem art born out of nonlinear dynamical systems — one could hardly name fields of physics further apart than these. Nevertheless, there exist features common to these seemingly unrelated topics, features that were the subject of a recent meeting*. All the systems are affected in one way or another by noise or chaos: quantum noise in all its modifications, quenched, squeezed, inhibited or enhanced; noise as a factor in quantum measurements causing the irreversible destruction of interference fringes, a fate compared by J. Schwinger and colleagues to the irreversible one of Humpty Dumpty falling off the wall; classical noise triggering the switching of a bistable system; and the deterministic analogue of noise — chaos — arising in nonlinear systems.

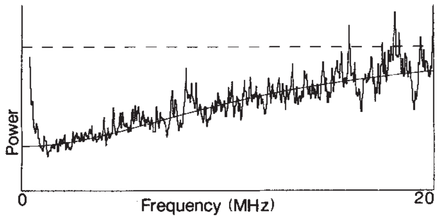

FIG. 1 Noise reduction factor R as a function of the frequency Ω for the intensity difference between the two beams in the optical parametric oscillator experiment of C. Fabre *et al.*. The dashed, horizontal line at unity corresponds to the vacuum level; the jagged, experimental curve, in good agreement with the solid theoretical curve, shows 69 per cent noise reduction around 2 MHz. (From T. Debuisschert *et al. Quantum Optics*; in the press.)

Noise is ubiquitous in physical systems, generally being regarded as a nuisance. But increasingly it is becoming the subject of studies in its own right: as an aspect of chaos in dynamical systems; and as an aspect of the uncertainty principle and indeterminism in quantum systems. As it becomes better understood, long-standing problems in diverse topics are being solved and subtle new approaches to noise suppression are being devised.

The latter benefit can be illustrated by developments in the search for astrophysical gravitational waves. These are supposed to leave their signature in relative changes of length as little as 10^{-21} of heavy, aluminium 'Weber' bars or in tiny shifts of interference fringes in a Michelson interferometer. The zero-point oscillations of the Weber cylinder or of the electromagnetic field, which tend to mask the effect, have consequently stimulated new discussions in the quantum theory of measurement and have boosted studies of nonclassical radiation fields, such as squeezed states (see the News and Views articles by D.F. Walls in *Nature* **324**, 210–211; 1986; and R.K. Bullough in *Nature* **333**, 601–602; 1988).

The ultimate aim is to follow a quantum system, such as a Weber bar oscillator, in time by making repeated measurements on it at discrete intervals, and to deduce from its evolution, or 'trajectory', the (gravitational) force acting on it. But what does it mean, to make a measurement? An answer is offered in the following procedure: start from a quantum system such as a free particle driven by a short pulse — the gravitational wave; couple it at discrete times to a heavy detector — a meter to follow its motion; and apply a modified Dirac–von Neumann wavefunction-reduction hypothesis, according to which a measurement of a meter variable reduces the *combined* wavefunction of system and meter to a pure wavefunction of the system alone. The meter variable is no longer a dynamical variable but solely a parameter. These are the ingredients of W.E. Lamb's (Univ. Arizona, Tucson) operational prescription for sequential measurements on a quantum particle. According to newtonian physics, the particle initially at rest moves with constant velocity after the action of the gravitational pulse. Although quantum mechanics rejects the notion of such well defined trajectories, the result of the quantum version of this problem, evaluated according to the above recipe, is very similar so that one can determine the smallest detectable gravitational force.

The subtle relationship between noise and quantum measurement can also be illustrated by lessons learnt from quantum optics. An oscillator in a coherent state, such as light from a laser, has its zero-point fluctuations — reflecting the Heisenberg uncertainty — distributed equally over the two conjugate variables electric field, E, and magnetic field, H. But why distribute them equally? Why not squeeze the fluctuations from E into H, or vice versa? An experiment measuring only the variable of reduced, that is, squeezed fluctuations must be superior to the corresponding one tackling the coherent state. The experimental realization of such squeezed states — now obtained in many laboratories — relies (P.L. Knight, Imperial College) on nonlinear optical processes such as four-wave mixing or the parametric oscillator. In the latter case, a photon of frequency 2ω creates two photons each of frequency ω. Because the twin photons are born out of a single photon, there exists a strong correlation between them, consequently reducing the quantum noise in the difference between the two beam intensities by as much as 69 per cent, as shown in Fig. 1 (C. Fabre, Ecole Normale Superieure, Paris).

One- or two-photon 'micromasers' (S. Haroche, Yale Univ.) can allow intriguing tests (M. O. Scully, Univ. New Mexico) of the complementarity principle (according to which wave- and particle-like descriptions are complementary). Send an atom prepared in a coherent superposition of two quantum levels through two consecutive micromasers as shown in Fig. 2. In this way, transfer the population to two neighbouring levels. Is the initial coherence between the two atomic states as manifested in an oscillatory ionization signal — temporal interference — preserved? To elucidate this question, imagine starting from coherent cavity fields with a large mean number of photons. In such a coherent state the fluctuations in photon number are large. Hence the two photons emitted in the transfer process, and caught in the cavities, do not change the field state significantly. One cannot deduce information concerning the transfer by studying the cavity fields and hence the coherence is preserved giving rise to quantum beats. However, if the experiment is started from a state of well-defined photon number, it is possible to detect the

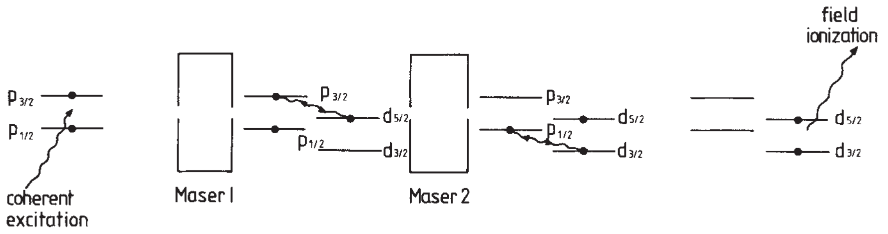

FIG. 2 The micromaser '*welcher weg*' ('which path') detector of Scully and Walther. In passing through the first micromaser a Rb atom, prepared in a coherent superposition of $63p_{3/2}$ and $63p_{1/2}$ makes a transition from $63p_{3/2}$ to $61d_{5/2}$; and in the second, from $63p_{1/2}$ to $61d_{3/2}$. Depending on the maser state — coherent or number state — quantum beats detected via field ionization do or do not occur. (From M.O. Scully & H. Walther, *Phys. Rev.* A; in the press.)

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increase, by one, in photon number induced by the population transfer. This destroys the coherence of the state, just as identifying which slit a photon passes through in the Young's double-slit experiment destroys the coherence and hence the interference fringes in that experiment. Bohr's standard explanation for the phenomenon involves arguments about the random phase of photons which, in this micromaser cavity experiment, are clearly inapplicable.

Classical studies of chaos have arisen as it becomes clear that noise is not necessarily a random, or stochastic, effect but arises from the complicated, but deterministic, dynamics of nonlinear systems. The paradigm for classical chaotic systems is turbulent flow in a fluid, which arises when nonlinear viscous effects dominate the smooth average velocity field of the fluid. A principal challenge is the calculation of the velocity fluctuations in fully developed turbulent flow, starting from the underlying equations of motion, the Navier–Stokes equations. It is the nonlinearity (in viscosity) of these equations — the very source of the apparently stochastic noise — that has frustrated theoreticians from solving analytically the flow patterns, so that numerical solutions have been sought instead. But S. Grossmann (Philipps Univ., Marburg) has found a way of decomposing the velocity field into two parts, one representing the smooth average velocity field, the other the fluctuating turbulence (which depends on the scale length of the decomposition). This analytic approach should allow a better understanding of the features of turbulence.

The phenomenon of stochastic resonance, used by Benzi *et al.* (*Tellus* **34**, 10; 1982) to try to account for a 10^5-year periodicity in the Earth's ice-ages was beautifully demonstrated (R. Roy, Georgia Inst. Technology) in a ring laser and in analogue electronic simulations (F. Marchesoni, Univ. Perugia). This seemingly counterintuitive effect occurs in bistable systems where it enables small periodic signals to be enhanced, astonishingly, by the addition of extra noise. In effect, the added noise helps the much smaller (but coherent) periodic components to push the system over the central maximum in the bistable potential, and hence leads to amplification. In the case of the ring laser, it was convincingly demonstrated that, with a periodically modulated asymmetry between the clockwise and counter-clockwise waves, the signal/noise ratio in the output increases markedly when noise is injected into the system. ☐

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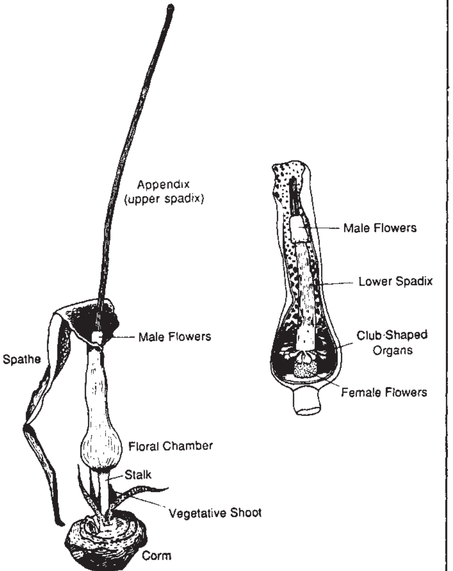
PLANT GROWTH

Hot sex in voodoo lilies

Jared M. Diamond

ALTHOUGH the use of metabolic heat to maintain body temperatures far above ambient is generally considered a hallmark of higher animals, particularly birds and mammals, it is also known to occur in flowers and inflorescences of at least six plant families, where a well-understood function of high temperature is to volatize compounds that attract insect pollinators[1]. *Arum* lilies such as skunk cabbage and the voodoo lily, for example, can increase the temperatures of their flowers in a brief burst by up to 22 °C above ambient. They thereby broadcast putrescent odours which have been compared with the smells of rotting flesh, decaying urine, faeces and sulphurous vapours[2], and which arise from volatile compounds including skatole, putrescine and ammonia[2,3]. A new study of the voodoo lily (*Sauromatum guttatum*) by Raskin *et al.*[4] now clarifies the triggering of heat production as well as revealing a second phase of heating with a separate function.



Inflorescence of the voodoo lily on D-day. Left, entire inflorescence; right, longitudinal cross section. (From ref. 4.)

The voodoo lily's inflorescence consists of a trap-like floral chamber containing the female flowers and club-shaped organs, accessible only via an opening containing the male flowers. Surmounting the floral chamber is a slender rod resembling a car's radio antenna, termed the appendix (see cover illustration). Until the day of blooming (D-day), the appendix is concealed within a sheath called the spathe.

The trigger for heat production turns out to be salicylic acid[5], whose concentration in the appendix begins to rise on the late afternoon of the day before D-day and peaks at 100 times the basal level. On the morning of D-day, the spathe unfolds to expose the antenna-like appendix (see figure), in which salicylic acid stimulates a metabolic explosion by the cyanide-insensitive mitochondrial respiratory transport system[6]. The resulting metabolic rate rivals that of hummingbirds in flight. Production of heat, and hence of stench, peaks between 3 and 5 hours after dawn on D-day. By late afternoon, the appendix's temperature has dropped back to ambient and its salicylic acid content has declined to basal levels.

The timing of this first phase of heat production depends on surges in three factors: salicylic acid production, tissue sensitivity to salicylic acid and light exposure, which enhances tissue sensitivity to the acid still more. (Until the spathe unfolds, the inside of the inflorescence remains dark.) Of 33 analogues of salicylic acid tested by Raskin *et al.*[4], the only ones that duplicate its stimulatory effect on heat production are acetyl-salicylic acid (aspirin), possibly because it is hydrolysed to salicylic acid, and the dihydroxy analogue of salicylic acid. The highest concentrations of salicylic acid are in the male and female flowers, but they do not produce heat. Thus, it remains unclear whether the acid is initially produced in the flowers and then transported to the heat-producing tissues of the inflorescence, or whether it is produced in the latter themselves.

The stench of the amines and indoles broadcast from the appendix lures insect pollinators to the floral chamber. From the night after D-day until dawn of the day after there is a second heating phase that differs from the first in originating between the male and female flowers in the centre of the floral chamber, producing less heat (temperatures 'only' 10 °C above ambient), and lasting longer (14 instead of 7 hours). Like phase 1, phase 2 is preceded and presumably triggered by a local 100-fold rise in levels of salicylic acid.

The heat of phase 2 stimulates activity of the insects attracted by the heat of phase 1 and trapped inside the flower chamber by the slippery concave walls and hedge of club-shaped organs. In addition, a sweet odour from the club-shaped organs may specifically stimulate insect mating behaviour. At the peak of phase 2, the male flowers shed their pollen into the

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