because the subject often has no call for expensive electronic wizardry, it is too often perceived as small, soft science, under the mistaken belief that a million-dollar piece of equipment must somehow be more important than teams of people to count greenfly. Yet more often than not, skilled pairs of hands are what ecologists really need to test and develop theory. The real irony is that because the subject is still viewed by some as a 'soft' science, we know far more about the stars, the inner workings of atoms and the human body than we do about the fragile, rapidly disappearing and increasingly fragmented ecosystems that are the life-support systems of our planet[13]. □

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Atomic physics

Single-atom masers and the quantum nature of light

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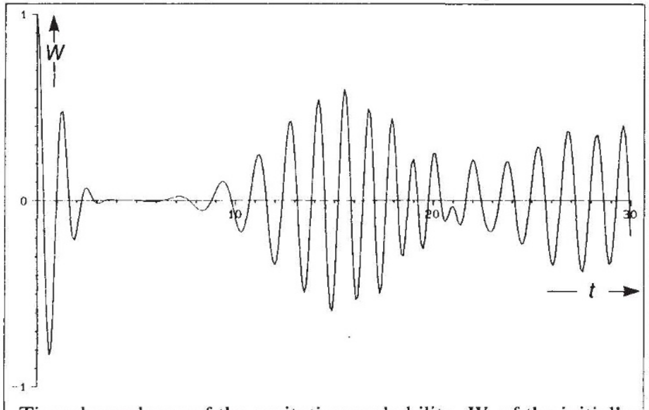
LASERS and their microwave relatives, masers, usually emit huge numbers of photons, so many that the discrete nature of the radiation is irrelevant to their behaviour. A classical continuously varying field with associated classical noise is perfectly adequate to describe almost all of the ill-named subject of quantum optics. A dramatic exception is provided by recent work (Meschede, D., Walther, H. & Müller, G. *Phys. Rev. Lett.* **54**, 551; 1985) on masers which comprise only a single atom and radiation fields so well that only two or three photons are present. This 'micromaser' can measure periodic energy exchange as a single photon is absorbed and re-emitted repeatedly in the maser cavity. Now, G. Rempe, H. Walther and N. Klein (*Phys. Rev. Lett* **58**, 353; 1987) report observations of the influence of photon statistics on Rydberg atoms in a cavity with a photon storage time so long that they can detect single-photon events. The authors detect quantum collapses and revivals of the maser coherent evolution, long believed to be a subject of interest only to theorists. These collapses and revivals are a fundamental quantum effect that depends entirely on the discrete nature of the photons in the maser cavity.



Time dependence of the excitation probability, W, of the initially excited atom, driven by an initially coherent field with $n = 5$. The Rabi oscillations are dephased by quantum fluctuations of the field, but partially revive later as the discrete nature of the field becomes evident.

An atom irradiated by a classical radiation field whose frequency is tuned precisely to an atomic transition frequency is excited to a higher energy level by stimulated absorption. Having achieved the excited state, the atom can be induced to return to the ground state by stimulated emission if the incident intensity of the radiation is sufficiently high, otherwise the atom emits its stored energy incoherently by spontaneous emission. The rates for these emissions and absorption were calculated in 1917 by Einstein. But if the radiation is sufficiently coherent, this simple rate picture is inadequate to describe the transition dynamics. Instead, the atom periodically and coherently exchanges energy with the radiation in a sinusoidal oscillation first studied by Rabi. Rabi oscillations are one of the basic concepts of quantum optics, and underlie present ideas about resonant excitation. The frequency of the Rabi oscillations depends on the magnitude of the electric field of the radiation.

When the radiation field is described by the laws of quantum mechanics, the continuously variable electric field is replaced by the discrete number of photons occupying that mode of the radiation field. A coherent field, rather than having a definite number of photons, has instead a Poisson distribution around a mean n with a width given by $\sqrt{n}$. Normally the photon number n is huge in laser physics and the fractional uncertainty in n is correspondingly unimportant. But an atom can, in principle, detect this uncertainty. Were there to be precisely m photons of a particular frequency interacting with an atom, the atom and field again exchange energy sinusoidally according to the ideas of Rabi.

The quantum Rabi frequency, first studied by E.T. Jaynes and F.W. Cummings in 1963 (*Proc. IEEE* **51,** 89; 1963), is analogous to the classical version, but has the electric field replaced by a quantity depending on the square root of the photon number m. States of the radiation field having precise numbers of photons are unknown. Instead we have to average over the probability distribution for there to be m photons in the interaction region. This leads to a collapse of the Rabi oscillations: the different possible photon numbers lead to a distribution of possible Rabi frequencies that dephase the coherent evolution. The dephasing is not irreversible. Because the photon numbers are discrete variables, the Rabi oscillations will rephase periodically. These revivals are the signature of field quantization (see figure).

To see Jaynes–Cummings collapses and revivals, it is essential to have an atomic transition that couples very strongly to the radiation. Rempe *et al.* used very highly excited Rydberg atoms with transition wavelengths in the sub-millimetre range. These atoms have dipole moments five orders of magnitude larger than normal microwave transitions (for example in the ammonia maser). The Rydberg atoms are produced by laser excitation of a beam of velocity-selected rubidium atoms. These highly excited atoms then enter a superconducting microwave cavity which supports a radiation field capable of resonantly exciting transitions to nearby Rydberg levels. Transitions are detected by ionizing the atoms as they leave the cavity in a static electric field: the number of ions detected depends on which atomic state is populated. Because the atoms are velocity-selected, the precise time available for coherent interaction with the field in the cavity is known. The probability of the atom remaining in its excited state is found to evolve exactly as predicted by the Jaynes–Cummings model. The sinusoidal Rabi oscillations at a frequency governed by the mean photon number are observed to collapse because of the distribution of Rabi frequencies. In the experiment of Rempe *et al.* the collapse was facilitated by a background thermal field with a broad distribution of photon numbers present in the maser cavity even at the temperature of the liquid-helium-cooled apparatus. At lower temperatures the Rabi oscillations persist for longer and a revival was observed. In these experiments there are on average only 2.5 photons in the cavity. That such a weak field is capable of being detected at all is a tribute to the skill of the micromaser experimentalists. □

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