A FAQ List for Circuit QED

In English, what did you do?
We built an integrated circuit (made with superconductors) which combines a single atom and a single photon. One part of the circuit is an element, called a qubit, which plays the role of the (artificial) atom. Another part of the circuit acts as a "cavity" which stores a single microwave photon. We observe that they combine to form a strange "molecule" which is both (and neither) qubit and photon at the same time, which one could call a "quton" or a "phobit."

What is an atom, and what do you mean when you say your circuit behaves like one?
An atom is a system which has discrete states, and can only go between those states by absorbing or emitting one photon. Our atom is artificial, and made by techniques used in fabricating integrated circuits, so it actually contains many (about a billion) atoms working in concert. But it's a "good" atom because it has only two states which matter, and because it can absorb energy and retain it for a relatively long time (actually only about a microsecond).

What is a photon?
A photon is a packet, or quantum, of light, containing a discrete amount of energy. The energy is proportional to the frequency (or color) of the light. Our photons are microwaves, with a frequency similar to that used in cell phones, and an energy that is 100,000 times less than a photon of visible light.

What's a molecule of atom and photon mean?
Ordinarily, an atom simply absorbs or emits a photon. When the photon is trapped by the cavity, the atom absorbs and re-emits the photon many times (more than ten, in our case).

Has an "atom-photon" molecule ever been observed before?
Yes, about ten years ago with "real" atoms and (visible) photons. This was a major achievement in "quantum optics," which is the study of how light interacts with matter. The trick is to convince the atom to interact very strongly with the photon, but not with anything else.

What's new or special about what you did?
While other artificial atoms have been demonstrated, this is the first one to be linked to a single photon. This is also probably the first time that a single photon is observed to disappear and reappear in a circuit. While ordinary atoms are small and hard to control and work with, our atoms are made artificially, and large enough to engineer. This ability to use microfabrication techniques and to engineer the system means that in future we might be able to make interesting combinations of atoms and photons that don't occur yet in nature.

What was the breakthrough that allowed it all to succeed?
We used the ability to engineer the circuit to create a relatively "large" atom, with an effective size about 10,000 times that of hydrogen, and a very small cavity, with a

volume equal to 1/1,000,000 of a cubic wavelength. This means that the photon collides with the atom very frequently, so that it can be absorbed and re-emitted quickly.

<u>What was hard about the experiment?</u>

The energy of the photons in our experiment is very small (1/100,000 of a photon of visible light). Any object at ordinary temperatures emits and absorbs a huge number of photons every second, just due to the fact that it is exchanging heat with its environment. We had to operate the circuit at a temperature of 0.02 degrees above absolute zero (10,000 times colder than room temperature), in order to avoid these extra photons. This also allowed us to build the circuit with superconducting wires that have no resistance, so we could make a cavity where the single photon could be stored for a relatively long time.

<u>What are the applications?</u>

One of the goals in quantum physics today is to develop a quantum computer, in which the transistors that store and process information as bits are replaced by single atoms or quantum bits ("qubits"), which can store and process the information quantum mechanically. Such a quantum computer, if it could be built, is predicted to have vastly enhanced speed and power for some special applications. So that the individual transistors in a regular computer can communicate with each one another, they are wired up by a "bus" which carries information back and forth. One way to wire up qubits in a quantum computer is to make a "quantum bus" using single photons. Our experiment demonstrates a possible way to do this with photons in a superconducting circuit, and so could be an important step in developing a quantum computer.

<u>What's a qubit?</u>

Any system which has two energy levels can be used to store information. This quantum element for information storage is called a quantum "bit" or "qubit," and unlike regular bits, it can exist in a superposition of both one and zero at the same time. Qubits are the basic building blocks of a quantum computer. Such computers don't exist yet, but are predicted to have enormous computing power for some tasks if they can be built. Trying to decide if and how a quantum computer can be built is one of the main goals of quantum physics today.

<u>What's a cavity?</u>

It's just a box in which a photon can be stored. With ordinary light, the box is made using mirrors which keep the photon in. In our case, the mirrors are replaced with superconducting wires, which keep the photon confined in a very small space.

<u>What is "circuit quantum electrodynamics"?</u>

Electrodynamics is the study of how matter interacts with electromagnetic fields and light. Cavity quantum electrodynamics is a field of atomic physics concerned with how atoms interact with quantized fields, i.e. with single photons, in a cavity. We've coined the analogous term "circuit quantum electrodynamics" to describe our realization of single photons and atoms all in a single electrical circuit.

<u>What does this tell us about quantum mechanics?</u> It still works. No, really.