ATOMTRONICS

The future technology

Atomtronics is the branch of science, engineering and technology that deals with the creation of analogues to electronic circuits and devices by the use of atoms. All of us are aware of electronics, mechatronics and spintronics, but the latest trend is atomtronics from physics lab—This technology develops circuits, materials and devices using ultra-cold atoms instead of electrons.

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Electronics deals with electron movement in the circuits governed by the use of wires, silicon and electricity. Transistors are the building blocks of all modern electronic devices. Until recently, electronics had been based on a single property of electrons—their charge. But now physicists have begun to exploit another property—electron spin.

So-called spintronics promises to revolutionize electronics because it allows information to be encoded in an entirely new way. Though electronics is bestowed with a large number of inherited advantages, but in the era of quantum electronics it is facing new challenges. Because electrons lose any possible initial quantum state as they bounce around through the energy-dissipating semiconductor or metallic systems, they are ill-equipped for quantum computing.

ATOMTRONICS
Why don't we use atoms in place of electrons in electronics devices ?

The aim of Atomtronics is to do just that by creating analogues to the common items found in electronic and spintronic devices. In 1924 Physicists Satyendra Nath Bose and Albert Einstein proposed that

"large numbers of atoms could be chilled to the point that they joined together in a single quantum state, bringing subatomic effects to a scale accessible by laboratory experiments".

Atomtronics is a young and emerging field based on the idea that atoms in unusual quantum states of matter may provide an alternative to the tried-and-true electron for making useful devices. The field's proponents have drawn up blueprints for atomic versions of many traditional electronic components—from wires and batteries to transistors and diodes. The idea is to manipulate neutral atoms using lasers in a way that mimics the behavior of electrons in wires, transistors and logic gates.

In Atomtronics, the current carriers in electronics (electrons) are replaced with neutral, ultra-cold atoms; the semiconductor material that the electrons traverse is replaced with an optical lattice; and the electric potential difference, which induces the flow of electrons around the circuit, is replaced by a chemical potential difference.

Over the last decade or two, physicists have become masters at creating optical lattices in which atoms can be pushed, pulled and prodded at will. This optical property of atoms has not attracted much attention of workers but now people have begun a program to put tame atoms to work. The problem is that atoms don't behave like electrons. So, building the atomtronic equivalent of something even as straightforward as a simple circuit consisting of a battery and resistor in series requires some thinking out of the box.

The dynamics of atoms in optical lattices, which are basically crystals of light, has been studied theoretically and experimentally for many years now. It is just a further addition to this field by theoretically demonstrating that the electronic properties of the diode and transistor can be observed in specifically tailored optical lattices.

Researchers believe that it is possible to emulate the behaviour of a semiconductor diode in these atomic systems. For example, simulations show that this augmented optical lattice will allow atoms to flow acros it from left to right, but forbids the atoms to traverse the lattice going the other way.

Ultra-cold atoms have interesting properties that conventional materials lack—superfuidity, superconductivity and coherence, to name just three. Being cold, they are also well-behaved enough to be manipulated by lasers. When several are held in a line or an array, these can link in a way that is governed by the laws of quantum mechanics and then the fun really starts.

These can be used to measure time on unimaginably short time-scales, can carry out simple calculations and may even form the basis of future quantum computers. Almost all of the atomtronics pioneers hope that for certain applications atoms will prove to be more interesting than electrons.

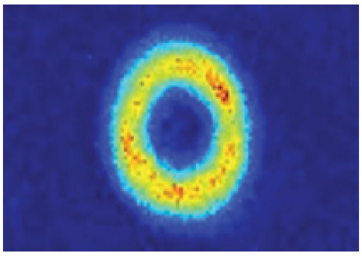

Fig. 1: Atoms spun by laser beams

The motivation to construct and study atomtronic analogues of electronic systems comes from several directions:

1. The experimental atomtronic realizations promise to be extremely clean. Imperfections such as lattice defects or photons can be completely eliminated. This allows one to study an idealized system from which all inessential complications have been stripped.

2. Atomtronic systems are richer than their electronic counterparts because atoms possess more internal degrees of freedom than electrons. Atoms can be either bosons or fermions, and the interactions between these can be widely varied from short to long range and from strong to

weak. This can lead to behavior that is qualitatively different to that of electronics.

3. Neutral atoms in optical lattices can be well isolated from the environment, reducing de-coherence. These combine a powerful means of state readout and preparation, with methods for entangling atoms. Such systems have all the necessary ingredients to be the building blocks of quantum signal processors. The close analogies with electronic devices can serve as a guide in the search for new quantum information architectures, including novel types of quantum logic gates that are closely tied with the conventional architecture in electronic computers.

4. Recent experiments studying transport properties of ultra-cold atoms in optical lattices can be discussed in the context of the Atomtronics framework. In particular, one can model the short-time transport properties of an optical lattice with the open quantum system formalism discussed here.

Latesr developments

The atoms placed in an optical lattice, when super-cooled to form Bose-Einstein condensates, may form states analogous to electrons in solid-state crystalline media such as semiconductors. Impurity doping allows the creation of n- and p-type semiconductor analogue states, and an atomtronic battery can be created by maintaining two contacts at different chemical potentials. Analogues to diodes and transistors have also been theoretically demonstrated.

Although atomtronic devices have yet to be realized experimentally, the properties of condensed atoms offer a wide range of possible applications. The use of ultra-cold atoms allows for circuit elements, which further allow for the coherent flow of information and may be useful in connecting classical electronic devices and quantum computers.

The use of Atomtronics may allow for quantum computers that work on macroscopic scales and do not require the technological precision of laser-controlled few-ion computing methods. Since the atoms are Bose condensed, they have the property of super fluidity and, therefore, have resistance-less current in which no energy is lost or heat is dissipated, similar to superconducting electronic devices. The vast knowledge of electronics may be leveraged to easily adapt to ultra-cold atomic atomtronic circuits.

Physicists have developed a new type of circuit that is little more than a puff of gas dancing in laser beams. By choreographing the atoms of the ultra-cold gas to flow as a current that can be controlled and switched on and off, the scientists have taken a step toward building the world's first' atomtronic' device.
The research team used Bose-Einstein condensate to make atomtronic sensors. The team reports creating this gas by cooling sodium atoms suspended in magnetic fields. Researchers then trapped the atoms in a pair of crossed laser beams and further chilled the atoms to less than 10-billionths of a degree above absolute zero. The two beams also shaped the condensate that formed at these low temperatures into a flattened dough-nut with a radius of about 20 micrometer.

Atomtronic devices

The atoms in the condensate flow as a current, which can be switched on and off like a normal circuit. Atomtronics uses atoms in strange quantum states to power devices or computer memory. This is different from spintronics, which stores information based on the spin of individual electrons, allowing each one to store two bits of data instead of one.

Computer scientists and particle physicists have made several advances in these fields in the past several months. Using atoms instead of electrons to process information could change the way we think about computing. In quantum computing we store a quantum state on an object, perform operations on the object and then read out the final state. If the system is not coherent, the initial stored information is lost.

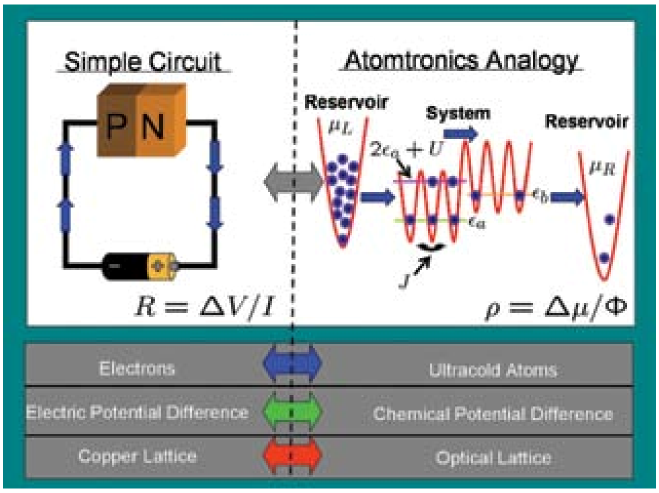

Fig. 2: Atomtronic analogy to diode circuit

Atoms trapped in optical lattices have been considered extensively for specific quantum computing schemes due to their inherent energy conserving characteristics. Therefore the dynamics of atomtronic devices would be coherent and potentially useful in quantum computing. It is also suggested that there is the possibility that atomtronics could be useful in obtaining sensitive measurements. It is thus concluded that atomtronic systems provide a nice test of fundamental concepts in condensed matter physics. While these ideas have been modeled, they are yet to be built.

Atomtronic diode

Atomtronic diode is a device that allows an atomic flux to flow across it in essentially only one direction. The atomtronic analogy of a diode is formed from the joining of p- and n-type semiconductor materials. Electrons are replaced by ultra-cold atoms, the battery is replaced by high and low chemical potential reservoirs, and the metallic crystal lattices (the microscopic medium that the electrons traverse) are replaced by an optical lattice. The atomtronic diode is achieved by energetically shifting one-half of the optical lattice with respect to the other.

The wires and atomtronic components are composed of optical lattices, and current refers to the number of atoms that pass a specific point in a given amount of time. The desired function of an atomtronic transistor is to enable a weak atomtronic current to be amplified, or to switch on or off a much larger one. The team has also modeled an atomtronic transistor. The atomtronic version of transistor exhibits on/off switching behavior and acts as an amplifier.

By configuring the optical lattice in a manner researchers show that it is possible to recover the characteristics of the conventional electronic transistor in the atomic world.

Limitations of atomtronics

Scientists are hoping to use the condensate in the way that superconductors have been used to make improved devices and sensors. Idea for a useful device was inspired by superconducting quantum interference devices, commonly known as SQUIDs. Scientists also believe that Bose-Einstein condensate could provide an extremely sensitive rotation sensor.

It is pointed out, however, that atomtronics probably won’t replace electronics as atoms are sluggish compared to electrons. This means it might be difficult to replace fast electronic devices with sluggish atomtronic device.