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Atomic clocks

Clocks measure time by counting off regularly repeated events, such as the Sun's motion across the sky, a pendulum's swing, or a quartz crystal's oscillations. The more frequent the event, the greater the potential accuracy of the clock. The most accurate timekeeping devices are atomic clocks, which are regulated by microwaves oscillating billions of times each second.

Most atomic clocks use atoms of cesium-133, an isotope of cesium. These atoms have two "spin states," according to whether the outermost electron is spinning in the same (parallel) or opposite (antiparallel) direction as the atom as a whole. These spin states have slightly different energies, and if microwave radiation of precisely the right frequency hits the atoms, they will flip from one state to the other. Cesium clocks are designed to "lock" an oscillator to this frequency, called the transition frequency, of 9,192,631,770 Hz.

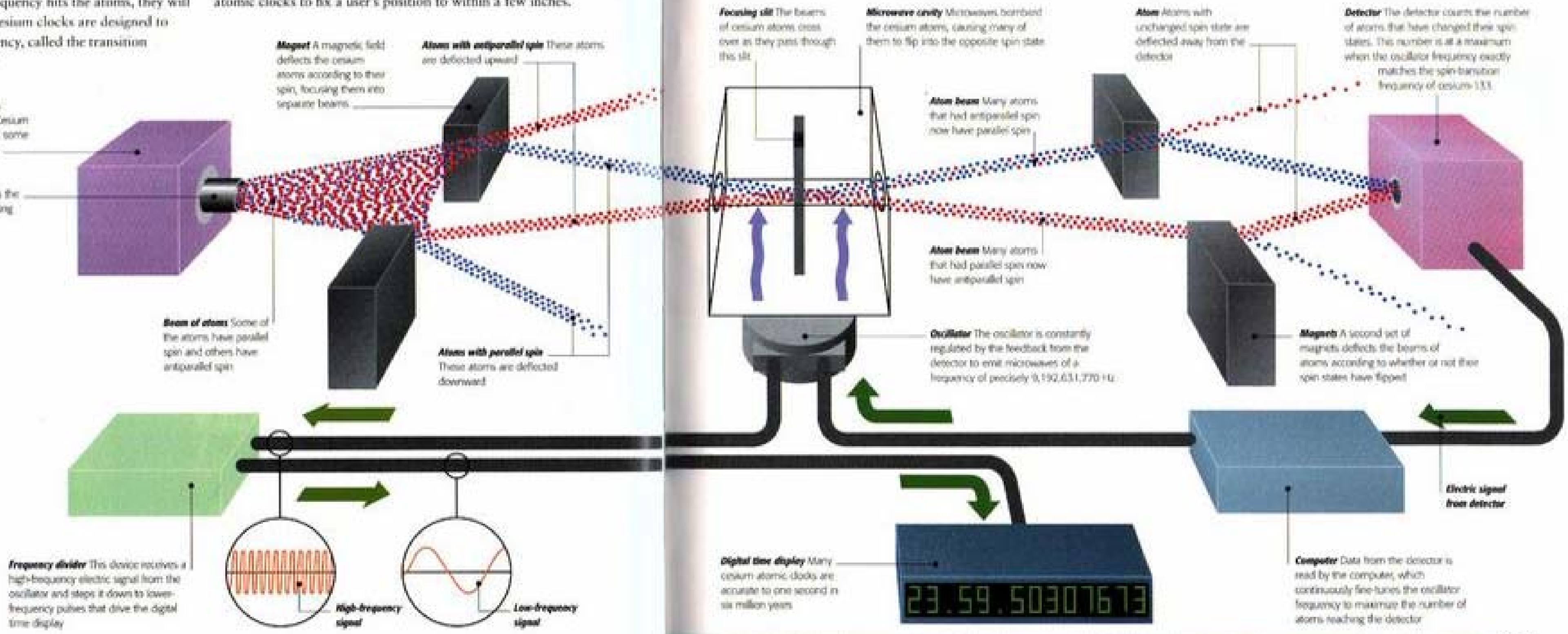
In a cesium clock, atoms are separated according to their spin state, then exposed to radiation from a microwave oscillator. A detector counts how many atoms have changed spin state. The greatest number of atoms change spin states when the microwaves are precisely tuned to the transition frequency. A computer uses signals from the detector to maintain the correct oscillator frequency, and pulses from the oscillator can be used to calibrate other clocks. Atomic clocks have revolutionized timekeeping, to the extent that one second is now defined in terms of the spin transition frequency of cesium-133 atoms.

Atomic clocks provide the timekeeping standard not just for scientific research, but also for the world's communication and transportation networks. The Global Positioning System, a satellite-based navigation system, relies on the accuracy of atomic clocks to fix a user's position to within a few inches.

NIST-7 atomic fountain
Currently, the most accurate timekeeping device is a type of atomic clock called the "atomic fountain," which tunes into the spin transition frequency of cesium-133 atoms, as do other atomic clocks. Its greater accuracy is obtained by using lasers to trap and cool a "pocket" of cesium atoms to just above absolute zero (the lowest possible temperature). The latest model, the NIST F-1, is accurate to one second in 20 million years.

Cesium clock

In a cesium atomic clock, a sample of cesium-133 is heated in an oven. Cesium atoms boil off the sample and emerge from the oven at high speed. These are focused by magnets into separate beams according to their spin state. The atoms pass through a microwave cavity, where most of them are flipped into the opposite spin state. The atoms are then deflected by a second set of magnets so that only the flipped atoms pass into a detector. A computer uses the detector signals to "lock" the microwave frequency. The entire clock is contained in an evacuated chamber.



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The Nobel Prize in Physics 2012

Serge Haroche, David J. Wineland

The Nobel Prize in Physics 2012

Serge Haroche

David J. Wineland

Photo: © CNRS Photothèque/Christophe Lebedinsky

Serge Haroche

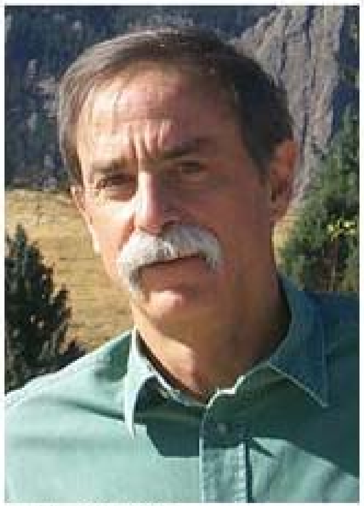

Photo: © NIST

David J. Wineland

The Nobel Prize in Physics 2012 was awarded jointly to Serge Haroche and David J. Wineland *"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"*

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雷射冷卻（Laser cooling)

台中縣縣立中港高級中學物理科王尊信老師/國立彰化師範大學物理系洪連輝教授責任編輯


朱棣文(Steven Chu)，美國華裔物理學家，1997年獲諾貝爾物理學獎，現任美國能源部部長。

在雷射冷卻(laser cooling)技術尚未發展出之前，僅能使用液態氦、液態氮等等的降溫技術，降低物質的溫度，這些技術不但耗時，效率也不高，然而在1986年，前中央研究院(簡稱中研院)的院士朱棣文等人研發了雷射冷卻技術，其可在室溫之下，將少量原子(約106~ 108個)的溫度，快速的降到10-6K，早期的技術只能降到10-3K左右，相較之下，雷射冷卻比起其他技術擁有更高的效率，並且使原子達到前所未有的低溫，因此替低溫原子的領域開起了一道大門，1997年，朱棣文和其研究夥伴共同獲得了諾貝爾物理獎。

降溫技術，都是降低粒子移動的速度，粒子所具有的動能越低，溫度自然就會越低，雷射冷卻不外乎如此，不過特別的是，雷射冷卻應用了都卜勒效應(Doppler effect)， 或稱都卜勒冷卻(Doppler cooling)，但基於此技術在室溫下進行，因此被降溫的粒子只能局限在某一塊區域，想像某原子在一維系統中運動，需要兩道雷射，並且調整雷射的頻率， 讓其低於原子躍遷的頻率，假設原子往右邊運動，將第一道雷射打向左邊(意即雷射指向的方向和原子運動方向相反)，將第二道雷射打向右邊(和原子的運動方向 相同)，當第一道雷射打到運動的原子時，因為兩個粒子(原子和光子)互相靠近，根據都卜勒效應，原子感受到雷射的頻率會增加，所以會越接近原子的躍遷頻 率，使原子能吸收其碰撞的能量， 往高能階躍遷，然而在高能階的原子，會產生自發輻射而回到低能階，不過自發輻射出的光，是往四面八方放射的，因此動量的平均值為零，但原子受到光子正面的 撞擊，動量降低，因此速度自然會減緩，使得原子溫度下降，而第二道雷射，因其方向和原子的運動方向相同，因此都卜勒效應並不明顯，並不會使原子發生躍遷， 只是確保原子向左運動時，仍會發生都卜勒冷卻，所以在三維空間下，粒子運動有六個方向，才需要六道雷射。

當一團原子在接近絕對零度的情況下，因為移動速度十分緩慢，所以動量很低，根據德布羅依的物質波概念，動量越小，原子的波長就越長，因此波動性會越顯 著，接著就會產生所謂的凝聚態，也就是所謂的波色-愛因斯坦凝聚(Bose-Einstein condensation，簡稱BEC)，此時絕大部份的原子都處於最低的能量態，此理論約在70年前由波色和愛因斯坦提出，但受限於當時的冷卻技術，無 法提供實驗的證明，終於到了1995年，美國物理學家才利用雷射

2.高瞻特輯-化學催化反應：
本系列文章譯自日本報導，由日本早稻田大學室井高城(Muroi Takashiro)教授撰寫，文章陸續上傳..歡迎閱讀!

科學新訊（2012/1/16)

7.7公釐青蛙 世界最小脊椎動物（自由時報）美國科學家11日宣布，他們在巴布亞紐幾內亞的熱帶島嶼發現一種身長僅7.7公釐的青蛙，摘下全世界最小脊椎動物頭銜。…more

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