Title
The Science of Cryogenics

Journal
Berkeley Scientific Journal, 19(1)

ISSN
1097-0967

Author
Catrini, Nick

Publication Date
2014

DOI
10.5070/BS3191025154

Undergraduate

The Science of Cryogenics

Nick Catrini

Have you ever wondered how NASA launched their monumental space shuttles? Or perhaps you have heard of the scientists who can slow the speed of light to almost zero? Or about Walt Disney's attempt at cryogenic stasis, where he waits to be awoken when a cure for lung cancer is developed? Unfortunately, Walt Disney being put into cryogenic stasis is a rumor and after his death he was cremated-but all three of these ideas have their roots in the field of cryogenics. Cryogenics is the art of achieving extremely low temperatures and observing phenomena that don't normally occur in the chaotic, energy rich universe we experience from day to day. People have been freezing things for ages, but the age has come where there's a demand for colder and colder temperatures, to the point where even the vacuum of outer space is a blazing inferno by comparison to what's needed in the lab today. Simply put, the colder you get to absolute zero, the easier it is to observe the true quantum nature of atoms, where generalizations and models made for atoms at room temperature begin to break down, and what's actually going on takes a different route. The ability to find and exploit these differences could lead to breakthrough technologies such as room temperature superconductors, quantum computers, improvements on existing technologies, and it could also answer questions about the origin and nature of the universe itself.

Liquid nitrogen is cold, space is colder, but what scientists need is in nanokelvin, billionths of a degree. One historic study that used ultracold temperatures focused on slowing the speed of light to seventeen meters per second in an ultracold atomic gas. The method of getting of the gas to be ultracold was the focal point of the study, since the colder it would get, the slower light would travel through it. The scientists reached a whopping 435 nanokelvin, but in a surprising way to the unfamiliar layman (Hau, 1999). In order to slow light down to seventeen meters per second, lasers were used to cool the atoms down to 50 microkelvin, and then a magnetic field was applied to the cloud of cold atoms to filter out any atoms that do not have magnetic dipoles against the field, creating an effect similar to a coffee cup cooling off, where the improperly aligned atoms steamed off and out of the magnetic field, or cup, and the remaining aligned ones were the only ones left (Marangos, 1999). Now, nanokelvin temperatures are great, but in some cases even nanokelvin is too hot for simulating some phenomena (Campbell, 2011). Again, atomic gases are cooled with lasers put into arrays called optical lattices that "trap" atoms and prevent them from moving, lowering the temperature.

> *"If quantum mechanics hasn't profoundly shocked you, you haven't understood it yet."*
> Niels Bohr

Now, why are scientists studying this again? As Niels Bohr once said, "If quantum mechanics hasn't profoundly shocked you, you haven't understood it yet." For one, the mere attempt to use advances in science and technology to tackle hard problems can lead to various discoveries in the process, such as the Bose-Einstein condensate or the slowing of light to 17 meters per second. But now, is the cost worth it? Slowing light promotes stronger light-matter interaction, which can benefit devices that clean up distortion and noise over long distance data transmission through optical fibers (Krauss, 2008). Last but not least, one of the most important discoveries in all of cryogenics' time is nuclear magnetic resonance imaging over scanning. That handful of words is better known as an MRI or PET scan you'd get at a hospital. MRI is revolutionary since it performs non-invasive imaging of anatomical structures with no known adverse biological effects, it can determine data not available by other techniques, and it increases the specificity of a diagnosis (Partain, 1984).

Research in these cooler temperatures today covers areas such as quantum magnetism and high temperature superconductivity, and the working memory needed for a quantum computer. The words "quantum computer" may sound very enticing, like some sort of science fiction mystery magic machine capable of solving any problem and running day to day tasks exponentially faster than even the most expensive supercomputer, but the reality is a stark contrast. In fact, the quantum computer got its roots in NMR-based technology (Ladd, 2010). A quantum computer is special because unlike a classical computer that has "bits" of information, a 1 or a 0, a quantum computer uses "qubits" which can be 1, 0, or anything in between. Qubits are particularly useful for a select set of problems, usually anything dealing with many

"An omni-linked world populated with intelligent artifacts will bring sweeping changes to virtually every facet of modern life – from science and education to industry and commerce – leaving no segment of society unaffected by its advance."
C. Altman

probabilities or variables, and in some cases can be faster than a computer the size of the known universe (Lanyon, 2010). However, outside of these special sets of problems, the qubit has no upper edge on a classical computer, and is actually less stable and more prone to error than its classical counterpart, making quantum computers something of a machine for the lab and big companies (Wang, 2011). NASA and Google already have some early models of functional quantum computers (Jones, 2013).

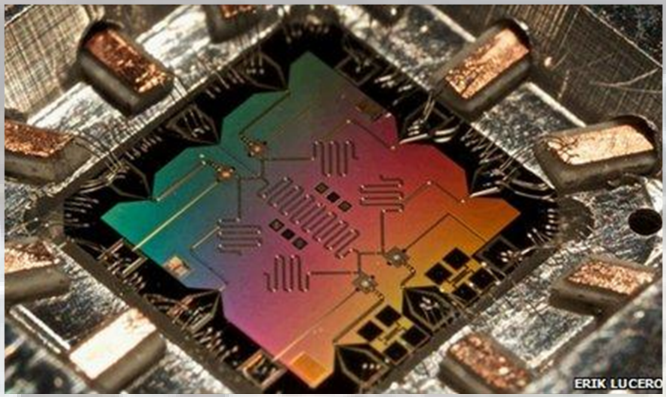

Figure 1. A quantum computer processor in action.

Cryogenics has a plethora of applications, but for the meantime, there is still much work to be done. The temperatures still aren't cold enough, and large scale quantum computing is impossible because of the large error rates (over 1%, in some cases). Error rates occur because no system is free of disorder, unwanted energy, and leakage, but either lowering that disorder or developing better error correction procedures will immensely improve the reliability of these new machines, which will lead to even more answers about the universe (Wang, 2011). If NASA didn't have cryogenically cooled hydrogen and oxygen fuel tanks to get into orbit, we would still be missing a lot of the things we have today-imagine what quantum computing (and the rest of cryogenic studies) can do.

References

Bakr, W. S., Preiss, P. M., Tai, M. E., Ma, R., Simon, J., & Greiner, M. (2011). Orbital excitation blockade and algorithmic cooling in quantum gases. Nature,480(7378), 500-503. Note: This paper is not cited directly, but it is the basis of Campbell's

Campbell, G. K. (2011). Atomic physics: When ultracold is not cold enough.Nature, 480(7378), 463-465.

Hau, L. V., Harris, S. E., Dutton, Z., & Behroozi, C. H. (1999). Light speed reduction to 17 metres per second in an ultracold atomic gas. Nature,397(6720), 594-598.

Jones, N., & Nature Magazine. (2013, May 17). Google and NASA Snap Up Quantum Computer D-Wave Two. Retrieved November 7, 2014.

Krauss, T. F. (2008). Why do we need slow light?. Nature Photonics, 2(8), 448-450.

Ladd, T. D., Jelezko, F., Laflamme, R., Nakamura, Y., Monroe, C., & O'Brien, J. L. (2010). Quantum computers. Nature, 464(7285), 45-53.

Lanyon, B. P., Whitfield, J. D., Gillett, G. G., Goggin, M. E., Almeida, M. P., Kassal, I., ... & White, A. G. (2010). Towards quantum chemistry on a quantum computer. Nature Chemistry, 2(2), 106-111

Leanhardt, A. E., Pasquini, T. A., Saba, M., Schirotzek, A., Shin, Y., Kielpinski, D., ... & Ketterle, W. (2003). Cooling Bose-Einstein condensates below 500 picokelvin. Science, 301(5639), 1513-1515. Note: Supplementary information on the same topic as Krauss.

Marangos, J. (1999). Slow light in cool atoms. Nature, 397(6720), 559-560.

Partain, C. L., Price, R. R., Patton, J. A., Stephens, W. H., Price, A. C., Runge, V. M., ... & James Jr, A. E. (1984). Nuclear magnetic resonance imaging. Radiographics, 4(1), 5-25.

Wang, D. S., Fowler, A. G., & Hollenberg, L. C. (2011). Surface code quantum computing with error rates over 1%. Physical Review A, 83(2), 020302

Image Sources

http://www.shutterstock.com/pic-130285649/stock-photo-digital-perspectives-series-abstract-design-made-of-numbers-light-grids-and-fractal-elements-on.html?src=GrswLy8vOyLIlx_hWcW2Mg-1-44

http://ichef.bbci.co.uk/wwfeatures/624_351/images/live/p0/15/7n/p0157nw3.jpg

http://news.bbcimg.co.uk/media/images/51778000/jpg/_51778327_51778326.jpg

Layout by Jacob Ongaro