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Inside...

Whither Helium?

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http://www.hydrogennow.org/Facts/Safety-1.htm

Iconic image of the 1937 Hindenburg disaster at Lakehurst New Jersey, which ended the age of hydrogen-based air transportation. Previous similar tragedies including that of the US Army dirigible Roma in 1922 led to the establishment of the US helium reserve, originally conceived as a strategic military asset.

HIGH ATOP the noble gas column of the periodic table, the buoyant and volatile helium is the second most abundant element in the universe, accounting for some *28% of all known mass*[1]. Yet here on Earth, as you have probably heard[2], the readily-recoverable supply is dwindling, prices are ballooning, and a crisis looms ahead for researchers and industries that depend on this unique and (in practice) nonrenewable resource.

At the IRM, as in many research labs, liquid helium is used as a refrigerant for superconducting magnets and SQUID sensors. A typical paleomagnetic laboratory consumes less than 100 liters of liquid He annually for continuous operation of a SQUID magnetometer; at the IRM we average over 10,000 liters a year for a suite of low-temperature high-field magnetometers/susceptometers and Mössbauer spectrometers, and our cost per liter has more than doubled in the last five years. The strong economic incentive to curtail our consumption has been supplemented on a few recent occasions by supplier-imposed rationing during acute shortages.

The helium problem will not go away, and is likely to continue worsening[3]. Together with our external Review and Advisory Committee (RAC), we have been thinking hard about short-, medium- and long-term strategies to keep the IRM viable as a community-based research instrumentation resource. Low-temperature phenomena including mineral ordering/phase transitions and blocking/unblocking of superparamagnets have become important parts of rock magnetic research and its applications in paleomagnetism and environmental magnetism.

A Brief Natural History of Element #2

ALL THE STARS IN THE NIGHT SKY are (or have been) busily burning hydrogen and producing light, heat, helium and heavier elements. Yet cosmologists tell us that the vast majority of the helium in the universe is (like helium) actually of pre-stellar origin, containing primordial nuclei forged in the first few minutes following the Big Bang, with relative numerical abundances ^{3}He : ^{4}He : H of approximately 10^{-5} : 0.1 : 1 (e.g., [1]). The weak gravity of our small planet is inadequate to retain light elements effectively, so helium is continually being lost from our atmosphere into space. At the same time, the isotope ^{4}He is continually being produced by alpha decay of ^{235}U, ^{238}U, ^{232}Th and other radioactive isotopes in the Earth's crust (and to a lesser extent, in the deep interior).

To first order we can think of terrestrial ^{3}He as primordial gas trapped in the mantle, and the much-more-abundant ^{4}He as a mixture of radiogenic crustal and primordial mantle components. Helium makes its way from the Earth's interior to the surface in various ways, and variations in the isotopic ratio provides important information bearing on internal reservoirs and transport processes[4].

For reasons that are not precisely known, the richest source of helium on Earth is the natural gas fields in the

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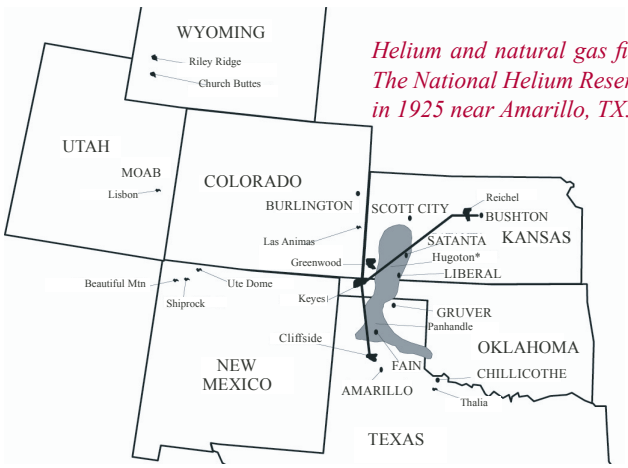

Helium and natural gas fields and pipelines. The National Helium Reserve was established in 1925 near Amarillo, TX. (Source: USGS[3])

Visiting Fellows' Reports

A peculiar 35K pyrrhotite transition in mature claystones

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In the framework of radwaste disposal programs, we investigated the rock magnetism, physical properties, petrology and geochemistry of immature and mature claystones. The Callovian-Oxfordian Bure claystones (BC) crop out in the Basin of Paris (France) and they experienced weak thermal burial at ~40°C. By contrast, Aalenian Opalinus claystones (OC) crop out at ~250 km south of Bure in the Jura fold-and-thrust belt (Swiss). Opalinus were heated at ~90°C during the peak Cretaceous burial. The mineralogy of these claystones is similar, apart from the ratio of smectites and illites. The thermal demagnetization of composite IRM (hard, medium and soft coercivities) indicates that magnetite is a common magnetic carrier of both claystones. However, a marked inflexion at ~320°C in BC suggests the occurrence of iron sulfide. Esteban et al. (2006) proposed that this iron sulfide is greigite. The ~320°C inflexion is less marked for OC and the occurrence of magnetic iron sulfides has never been described to date. One main goal of this study is to identify the nature of iron sulfides in Opalinus claystones.

At the IRM, we carried out low temperature runs of SIRM (MPMS) and hysteresis loops (VSM). We show RT-SIRM, ZFC and FC of the two claystones (figure 1). In BC, the Verwey (~118K) and Morin (~250K) transitions point to the presence of magnetite and hematite respectively (Figure 1A). ZFC and FC of BC show a continuous drop in magnetization between 10K to 300K with slight evidence of Verwey transition (Figure 1C).

In OC, we identify the Verwey transition (magnetite) and a ~30% drop of RT-SIRM below 50K (Figure 1B). Interestingly, one can see that the transition is well marked at ~35K (Figure 2B). This transition is peculiar because 1) it does not show an 'S' pattern; 2) it is perfectly reversible. At first glance, this transition looks therefore like a paramagnetic input induced by a trapped magnetic field in the MPMS. Two remarks should be made at this stage: 1) the trapped field is low in the MPMS (less than 500 nT) and a strong paramagnetic input is thus unlikely, 2) The Bure claystones, with similar paramagnetic mineralogy to OC, do not show the 35K transition (Figure 1A). Actually, the 35K transition is well constrained in all measured Opalinus samples (Figure 2A). We have corrected the signal from an eventual paramagnetic trend (e.g. Figure 2B). This correction does not change the whole pattern of the transition, except the amplitude. Thus, this transition is not a mere paramagnetic input of clays.

The 35K transition is well observed in ZFC and FC experiments where ~95% is lost between 10K to 50K (Figure 1C). This transition can be due either to pyrrhotite (~35K) (Dekkers et al., 1989; Rochette et al., 1990) or siderite (~40K) (Housen et al., 1996). Siderite, with a concentration of ~2% in Opalinus claystones, is a plausible candidate for this transition. However, two observations support the pyrrhotite hypothesis. First, Pan and Symons (1993) report a sharp increase of RT-SRIM during cooling at ~40K, which contrasts with the observed drop of RT-SRIM. Second, Housen et al. (1996) show that FC remanence is much higher than ZFC remanence by an order of magnitude at 10K. Such FC and ZFC difference is not observed in our samples (Figure 1C). According to Dekkers et al. (1989), the perfect reversibility of RT-SRIM cooling and warming curves points to very fine fraction of pyrrhotite (blocking volume of pyrrhotite is ~1 µm).

Pyrrhotite is thus identified in Opalinus claystones, in combination with magnetite. The hysteresis loops of this magnetic assemblage display marked transition at ~35K during the 300K-10K cooling (Figure 2C). The saturated remanent magnetization Jrs shows a large increase at ~35K. The coercive field Bc is decreasing from ~50 mT to few mT from 300K to ~35K. Then Hc is increasing again between 35K to 10K (~10 mT). Jackson et al. (1993) pro-

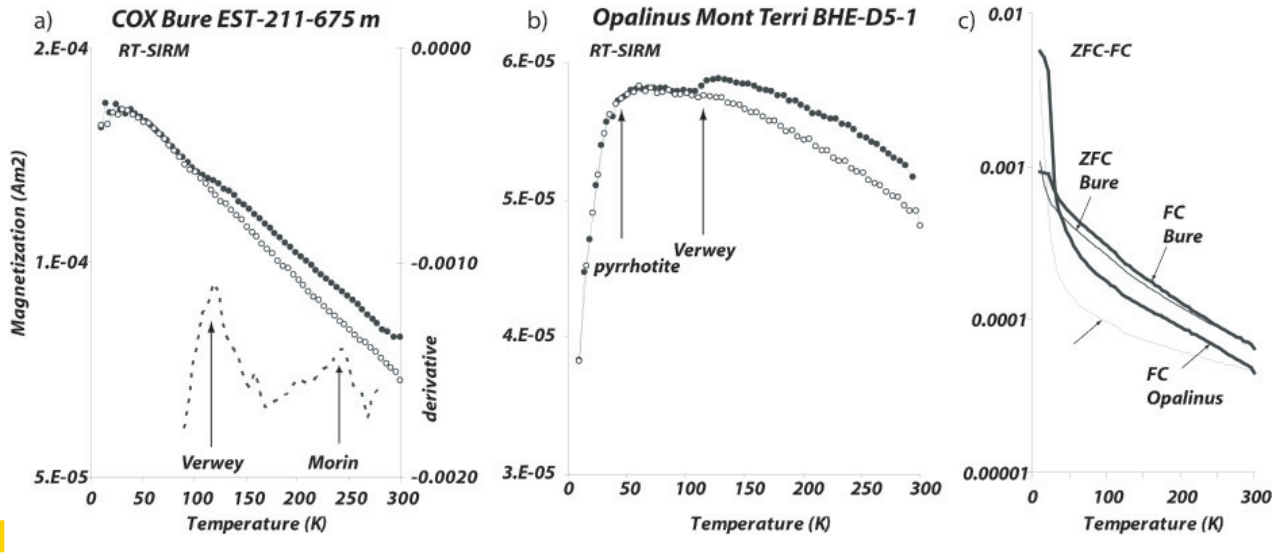

Figure 1

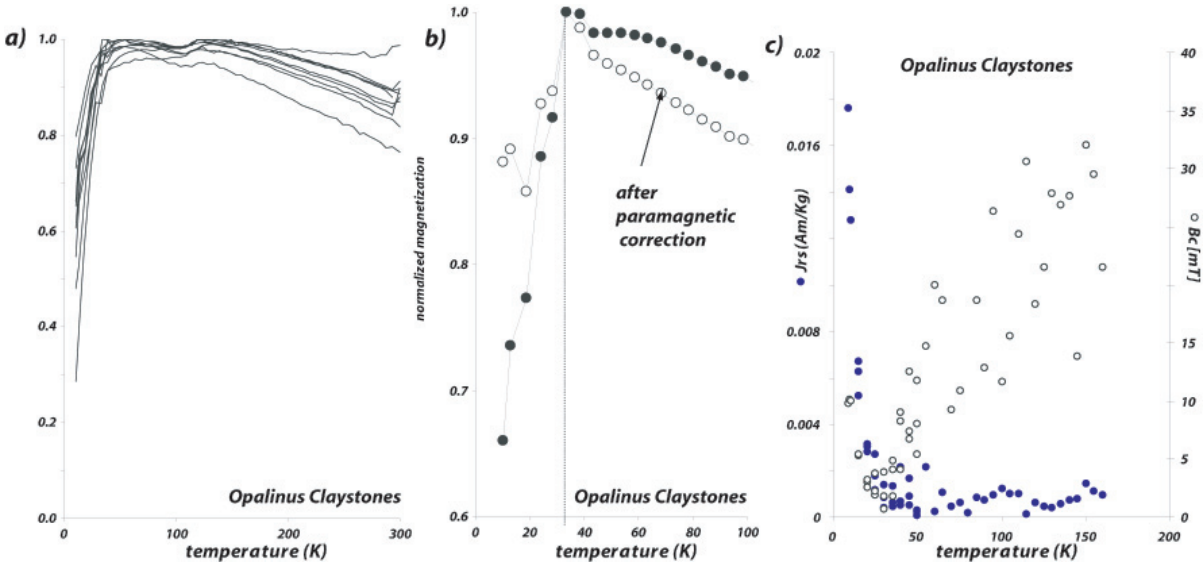

Figure 2

posed to compare different ratios to distinguish between magnetite-bearing rocks and pyrrhotite-bearing rocks. The ratio Kf/Ms (Kf ferromagnetic susceptibility, Ms : magnetization at saturation) and Ka/Kf (Ka anhysteretic susceptibility) show the following trends : $Kf/Ms_{magnetite} > Kf/Ms_{pyrrhotite}$ and $Ka/Kf_{pyrrhotite} > Ka/Kf_{magnetite}$. We found $Kf/Ms_{Bure}=41\pm20$ m/A $< Kf/Ms_{Opalinus}=140\pm131$m/A and $Ka/Kf_{Bure}=1.2\pm0.8 > Ka/Kf_{Opalinus}=0.4\pm0.1$. These parameters contradict at first glance our findings that pyrrhotite occur in Opalinus, and not in Bure. However, in Bure, the greigite plays probably a significant contribution to the magnetization and in turn, changes the ratios. In addition, we think that most of pyrrhotite in Opalinus claystones is in superparamagnetic state, leading to little contribution to remanence (both anhysteretic and isothermal magnetizations). We think that the very fine fraction of pyrrhotite is marked by the peculiar 'paramagnetic like' transition at 35K. The very fine fraction of pyrrhotite points probably for a secondary origin.

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Crustal magnetization and magnetic petrology from hot-spot related basalts - an approach from low-T magnetic measurements and magnetic force microscopy

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During the visit to the IRM we wanted to address two main goals. The first one was to better characterize the chosen samples by means of low temperature measurements (AC and DC analyses) and the second one was to better characterize the possible differences among the samples by magnetoptical observations (MFM and MOKE). Doing so, a better understanding of the influence of secondary process (e.g. high- low-T oxidation, hydrothermal alteration) for the magnetization of basalts is explored.

The samples are basalts from Hawaii (HSDP) and Iceland (IDDP) continental drilling programs. Three pairs of samples were chosen depending on the degree of maghemitization. Every pair shows different grain sizes (microscopical observations with ferrofluid, SEM). The magnetic phases and textures were previously studied with χ-*T* curves and SEM. One pair from Hawaii shows different NRM but the same primary Ti rich titanomagnetite as the main magnetic carrier. Another pair of samples (one from Hawaii and one from Krafla, Iceland) has different susceptibility with similar low NRM in maghemitized

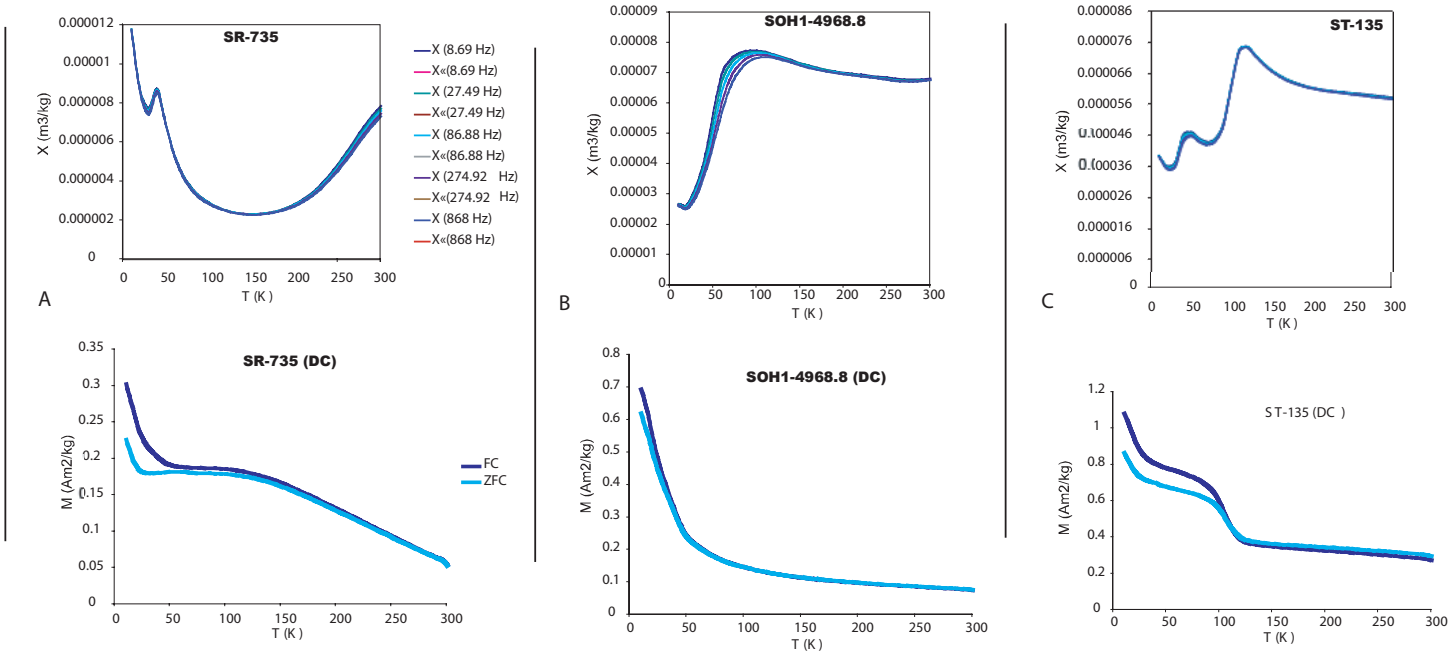
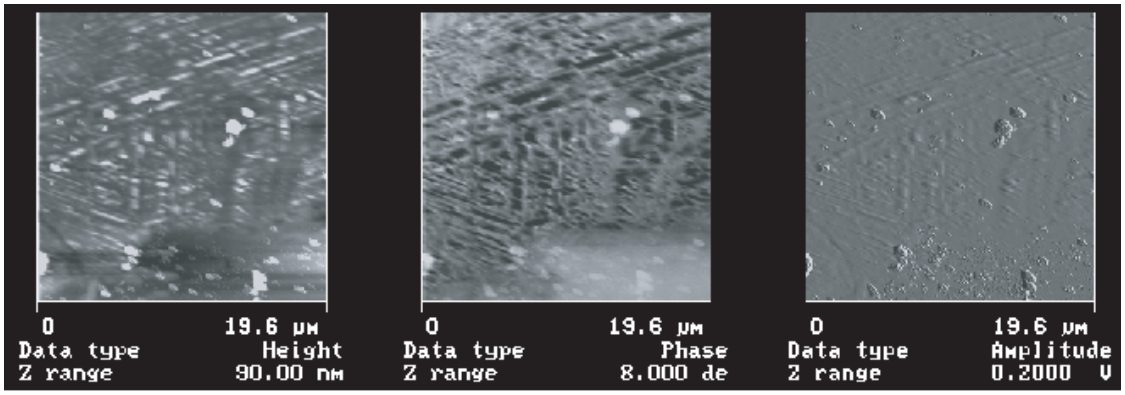


Figure 1 (above): AC measurements (in-phase susceptibility) above and Field Cooling-Zero Field Cooling curves below for the three pairs. A. Fresh Ti-magnetite from Hawaii. B. Maghemitized sample with high-T oxidation from Hawaii. C. Sample with almost pure magnetite (Ti-poor) from Stardalur (Iceland)



ST135 (Stardalur)

Figure 2 (right). MFM images after 200 mT demagnetization of a sample with high- and low-T oxidation but almost pure magnetite (Ti poor). The magnetic image in the center (Phase) follows the topographic features (Height and Amplitude images) related to the different phases within the grain. White spots of silica particles lie out on top of the sample and are artifacts due to preparation

samples where also high-temperature oxidation took place. The third pair of samples from Stardalur (Iceland) shows extremely high NRM in samples with almost pure magnetite (Ti poor titanomagnetite) and some maghemite with also high-T oxidation (Vahle et al., 2007).

As a first approximation, a clear difference among the three pairs of samples in both AC and DC measurements was observed (figure 1).

A closer examination of the in-phase and out-of-phase 5-frequency measurements and the FC-ZFC/SIRM analyses will provide more information about the low-temperature oxidation process and the further inversion to magnetite mechanism in hydrothermal settings comparing to the fresh primary titanomagnetites from Hawaii and Iceland.

The samples were difficult to observe under the MFM (Magnetic Force Microscope). After demagnetization, two of the six samples gave some results, related to the exsolution lamellae (high-T oxidation, figure 2). The samples with smaller grains did not give any magnetic results in the phase image, neither after the demagnetization at 200 mT. Since MFM was not very successful, MOKE was not used.

Finally, B.O. wants to thank the IRM people for their welcoming hospitality, especially Peat and Thelma.

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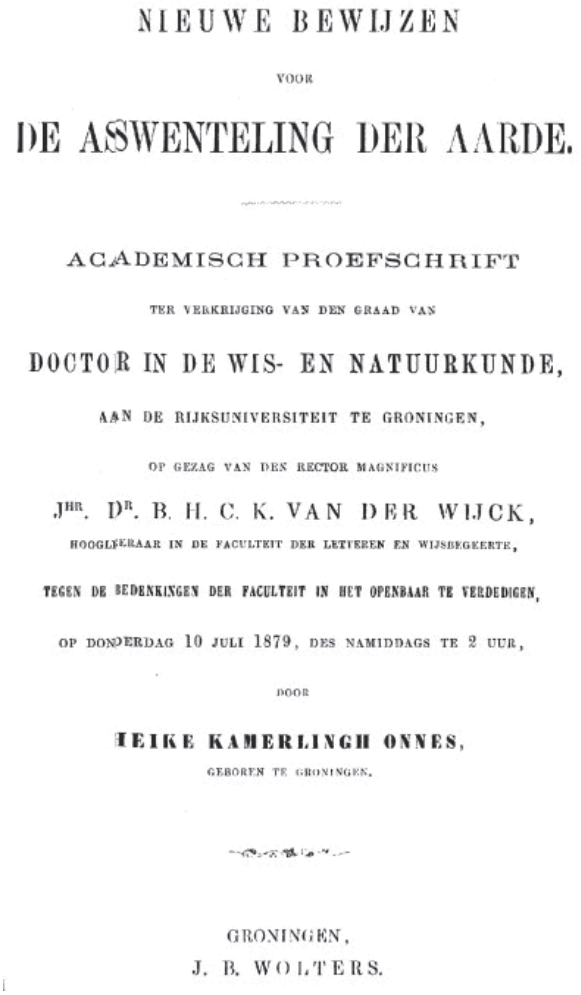

NIEUWE BEWIJZEN

VOOR

DE ASWENTELING DER AARDE.

ACADEMISCH PROEFSCHRIFT

TER VERKRIJGING VAN DEN GRAAD VAN

DOCTOR IN DE WIS- EN NATUURKUNDE,

AAN DE RIJKSUNIVERSITEIT TE GRONINGEN,

OP GEZAG VAN DEN RECTOR MAGNIFICUS

JHR. DR. B. H. C. K. VAN DER WIJCK,

HOOGLEERAAR IN DE FACULTEIT DER LETTEREN EN WIJSBEGEERTE,

TEGEN DE BEDENKINGEN DER FACULTEIT IN HET OPENBAAR TE VERDEDIGEN,

OP DONDERDAG 10 JULI 1879, DES NAMIDDAGS TE 2 UUR,

DOOR

HEIKE KAMERLINGH ONNES,

GEBOREN TE GRONINGEN.

GRONINGEN,

J. B. WOLTERS.

Current Articles

A list of current research articles dealing with various topics in the physics and chemistry of magnetism is a regular feature of the IRM Quarterly. Articles published in familiar geology and geophysics journals are included; special emphasis is given to current articles from physics, chemistry, and materials-science journals. Most abstracts are taken from INSPEC (© Institution of Electrical Engineers), Geophysical Abstracts in Press (© American Geophysical Union), and The Earth and Planetary Express (© Elsevier Science Publishers, B.V.), after which they are subjected to Procrustean culling for this newsletter. An extensive reference list of articles (primarily about rock magnetism, the physics and chemistry of magnetism, and some paleomagnetism) is continually updated at the IRM. This list, with more than 10,000 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the IRM Quarterly are always welcome.
(List compiled by Thelma Berquó, December 2007).

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Helium, continued from page 1

south-central plains states of the US (Kansas, Oklahoma and Texas). Natural gas from wells in the Hugoton-Panhandle region contains helium in concentrations up to 8%. Nowhere else on Earth are concentrations found exceeding 0.1%, and until recently virtually all of the global He supply came from the Panhandle fields[5,6].

Some Physics and Chemistry of Helium

A BRIGHT YELLOW SPECTRAL EMISSION LINE (587.49 nanometers) in sunlight, first observed by Pierre Janssen in August 1868 and soon thereafter independently by Norman Lockyer, provided the first evidence of the existence of helium. Lockyer and Edward Franklyn recognized it as an element not known on Earth and named it for its type locality, the sun. Helium was first found on Earth in 1895 when William Ramsey isolated it by acid treatment of the uranium-bearing mineral cleveite (named for Per Teodor Cleve, who soon collected enough helium to determine its atomic weight). By 1903 helium had been found to occur in significant quantities in gas wells in Kansas.

The "noblest" or most inert of the full-electron-orbital gases, helium has the highest ionization potential of any element. ^{4}He also has a notably stable nucleus, with a "doubly magic" number of nucleons (2 protons and 2 neutrons representing full nuclear shells)[7].

Helium has the lowest boiling point (4.2K for ^{4}He and 3.2K for ^{3}He) and is the only substance that remains liquid at a temperature of absolute zero (solid helium is stable only at pressures above a few MPa, i.e., 20-30 atmospheres). At the lambda point (~2.2 K for ^{4}He, and less than 1 milliKelvin for ^{3}He at atmospheric pressure), liquid helium undergoes a transition to a superfluid state known as Helium II, with essentially zero viscosity, enormous thermal conductivity (the highest of any known substance) and other exotic, classical-physics-defying properties[8,9].

Temperatures down to about 1 K can be reached by "conventional refrigeration", i.e., by compression/expansion cycles and heat exchangers. Lower temperatures are reached by techniques including "dilution refrigeration" down to the milliKelvin (mK) range, and "adiabatic demagnetization", by which temperatures of a few microKelvin are attained[8]. In the latter technique,

liquid helium between copper plates is precooled to a few mK in a strong magnetic field; the spontaneous disordering of spins as the field is removed absorbs thermal energy.

The speed of sound in helium gas at room temperature is nearly three times as great as that in air, which is the reason our voices sound funny after inhaling helium, inadvertently or otherwise[10]. Like many other musical instruments, the human voice uses a primary oscillator and one or more resonant cavities to produce tones. The wavelength of the fundamental-mode resonant standing pressure wave is controlled by the size of the resonant cavity, and the fundamental frequency is determined by wavelength and speed.

Commercial and Scientific Uses of Helium[5,6]

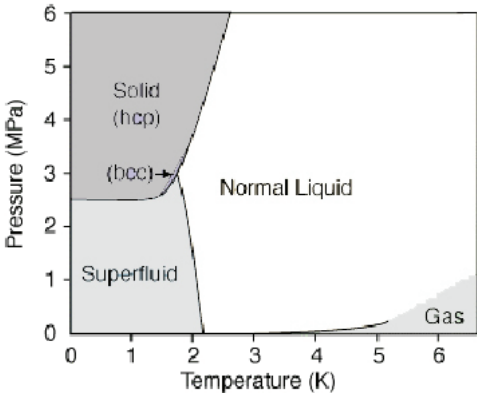
ROUGHLY ONE FOURTH OF HELIUM CONSUMPTION is for cryogenic applications including magnetic resonance imaging, low-temperture physics research, and the manufacture of silcon-wafer semiconductors. Another 20% or so has historically been taken up by the US space program, where it is used for pressurizing and purging the liquid hydrogen and liquid oxygen tanks in rocket propulsion systems. Helium is used as an inert shielding gas in industrial welding and for controlled-atmosphere manufacture of optical fibers and other materials; together these account for some 30% of annual consumption. Other uses include leak detection, "heliox" breathing-gas mixtures for deep-sea diving, and (of course) balloons.

Some interesting potential future uses are magnetic levitation (MAGLEV) and superconducting magnetic energy storage (SMES). Several superconducting MAGLEV train prototypes are in operation, including the JR-Maglev in Japan (which has attained record speeds of 581 km/h (361 mph)), and a high-Tc superconducting system in Chengdu, China. SMES devices store energy in magnetic fields associated with the loss-free flow of current in superconducting coils.

Helium Processing and Economics[5,6]

MINING THE ATMOSPHERE for helium (where it is present in a steady-state concentration of ~5 ppm, with crustal production balanced by diffusive loss) is not economically feasible, in contrast to the heavier noble gases Ar, Ne, Kr and Xe. Nor is it expected that direct extraction from air will become practical in the foreseeable future[11].

The essentials of helium extraction have not changed since the process was described in Time magazine in 1923: "*To isolate helium from uranium in commercial quantities would be impossible, but the more recent discovery that helium is a constituent of natural gas made possible the present-day developments. Its purification is one of the major problems. The best method (used at the Lakehurst, N. J., airship*



Phase diagram of ^{4}He (from [9])

station) is by passing the helium over charcoal at a low temperature, resulting in absorption of extraneous gases, leaving nearly 100% pure helium. Helium can be liquefied by cold, and is easily stored in that condition. A laboratory in Toronto is turning out liquid helium for military purposes."[12]

US government helium operations began and grew rapidly during the first World War, after which the responsibility for extraction, purification and storage was transferred from the military to the Federal Helium Program, administered by the US Bureau of Mines. New extraction and purification facilities built by USBM just north of Amarillo began operation in 1929[13].

Cold War strategic considerations in the 1950s motivated the next large expansion of helium operations. Amendments to the Helium Act in 1960 gave private-sector natural gas producers incentives to extract crude helium and sell it to the government. The accumulated gas (Federal Helium Reserve) was and still is stored at the Cliffside facility, in a geological structure known as the Bush Dome[14], near Amarillo. Some privately-owned helium is also stored there.

By the mid 1970s it had become apparent that demand was not keeping up with supply - the Reserve had reached a volume equal to several decades worth of consumption, and the production contracts were cancelled. By the 1990s, government demand for aerospace and other needs was far outpaced by private-sector use, leading critics to call for privatization. Humorist PJ O'Rourke wrote: "*I balanced the budget. It took me all morning but I did it. ...I tried to avoid looking for ridiculous examples of government waste. This is the first mistake made by most budget critics. They page through the minutiae in the* Notes and Appendices to the US Budget*, until they come up with something like the Dept of Interior's Helium Fund. Which really exists. ...The Helium Fund is amazingly stupid, even by government standards, but it only costs around $19 million — .0015% of 1991 federal spending.*"[15]

In 1996 Congress passed the Helium Privatization Act (Public Law 104-273), ending federal helium production and stipulating that "*Not later than January 1, 2005, the Secretary shall commence offering for sale crude helium from helium reserves owned by the United States in such amounts as would be necessary to dispose of all such helium reserves in excess of 600,000,000 cubic feet on a straightline basis between*

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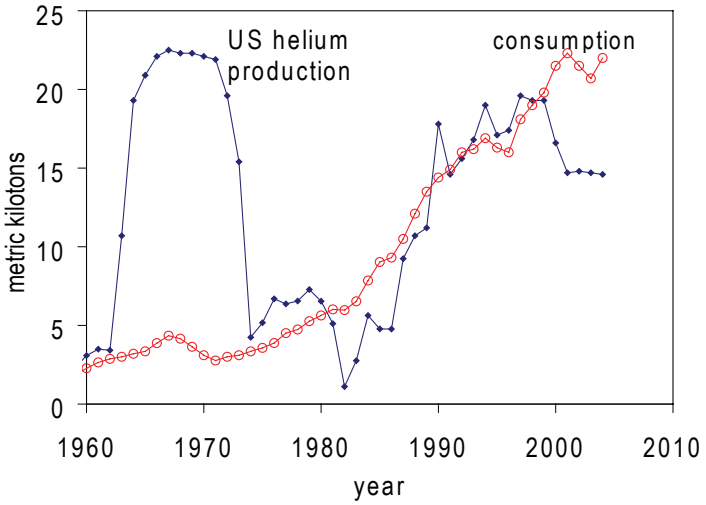

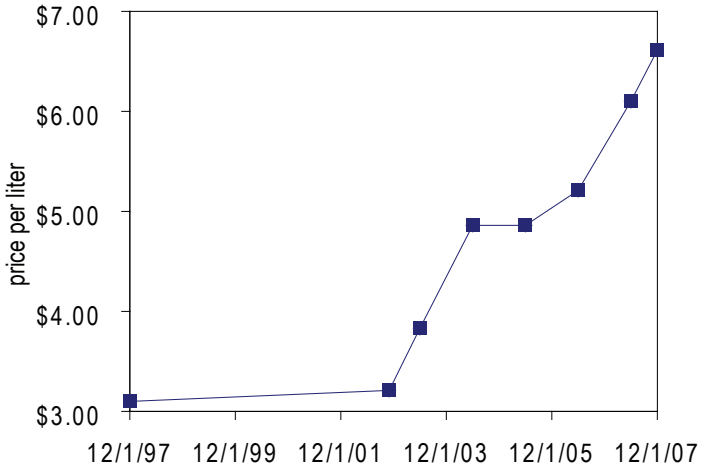

The Helium Privatization Act of 1996 mandated that US federal agencies cease production of Grade A helium by 1998, and sell the reserve supply by 2015. Since 1999 helium consumption has continued increasing, production has declined, and the projected continuation of both trends has led to sharp price increases. (left: data from USGS[5]; right: actual cost for helium use at the IRM).

Helium, continued from page 9

such date and January 1, 2015." It also commissioned a study by the National Academy of Sciences to evaluate the potential impact of this action on scientific research and on commercial interests.

The report[6], issued in 2000, concluded that privatization would "*not have a substantial impact on helium users*," but added uncertainty caveats and recommendations for follow-up studies. "*To remain in business and satisfy demand, the refining companies on the pipeline will first exploit their private stockpiles at the Cliffside facility. Once these private stockpiles are exhausted, the companies will have ... to begin purchasing the crude available from the Federal Helium Reserve.*" This was projected to occur some time between 2005 and 2020. It is now estimated that the Reserve is supplying ~35% of current global helium needs, and the other 65% is coming from private-sector production and remaining reserves[16]. "*Assuming no dramatic changes in the production and use of helium, however, the Federal Helium Reserve will still last for about 20 years or more, ...until approximately 2020 or 2025.*"

The rapid recent doubling of helium prices appears (at least to me) to be a prime example of an effect preceding its cause, which is prohibited in physics but commonplace in economics. Real shortages in the future are apparently inevitable, as demand continues, reserves are depleted, and production declines[17]. The era of disposable helium is on the way out.

Where Do We Go From Here?

EVENTUALLY THE COST OF HELIUM WILL BECOME PROHIBITIVE, and in the long term a new generation of high-Tc superconducting magnets and sensors will be required for medical technology and for basic scientific research. Meanwhile there are several short-term and intermediate-term measures that we are exploring for IRM operations.

The best intermediate-term solution is to recover and recycle helium rather than blowing it off into the atmosphere through pressure-relief boiloff valves and flow-through cryostats. Conservation of nonrenewable resources is of course an important goal even apart from any economic considerations; nevertheless significant infrastructural improvements require funding. Single-instrument helium reliquifiers are available for our Quantum Designs susceptometers, but for obvious reasons, university administrators and funding-agency officers are generally less excited about funding such infrastructural improvements than they are about new facilities or new instruments with new scientific capabilities. The NAS report noted "*For sufficiently large aggregations of research instruments and apparatus using liquid helium, such as might be found at major research universities, recovering and reliquefying helium boil-off gas could reduce helium consumption. This type of operation demands a substantial capital investment in a liquefier, a recovery system, and a helium storage facility, however, and at current helium prices, would be cost-effective only under special circumstances. Consequently, there is little incentive for most universities and laboratories to conserve helium by recovering it.*" Nevertheless the University of Minnesota has in fact established a liquification facility in our Physics Department, and we are currently investigating the feasibility (i.e., cost) of running a helium pipeline a few hundred meters through the campus steam tunnels, to reliquify much of our boiloff.

For some instruments, helium boiloff is not recoverable, e.g., our low-T VSM with its flow-through cryostat. Medium-term possibilities here include using a separate, currently-available liquid-nitrogen cryostat for measurements down to about 125K (liquid N boils at 77 K, but there are technical problems with temperature stabilization below 120-130 K). Princeton Measurements is also working on a new design for liquid-nitrogen cryostat with a wider range of operating temperatures[18].

Less palatable (but immediately implementable) measures include limiting usage of high-He-consuming instruments and/or charging user fees. For now our policy is to rely on voluntary measures by visiting scientists (and harder limits on in-house research) to reduce helium consumption. In practice this means critical experiments with well-defined objectives can go forward, but more exploratory or speculative studies will have to be discouraged.

The last decade has seen a great surge of interest in the low-temperature magnetic behavior of remanence-carrying minerals, nanophase materials, biomagnets and other natural and synthetic substances. Together with strong magnetic fields, low-temperature measurements allow for nondestructive characterization and give us effective experimental tools for probing the physical origins of magnetic stability. Maintaining these capabilities at the IRM is important for the geomagnetism/paleomagnetism/rock-magnetism community, and we are doing everything we can to ensure continued access to these resources.

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8. Lancaster University low-T physics site *http://www.lancs.ac.uk/depts/physics/research/condmatt/ult/index.htm*
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10. Helium inhalation can be dangerous, due to possible contaminants and to the risk of asphyxiation. "The breathing reflex is triggered by excess of carbon dioxide rather than lack of oxygen, so asphyxiation by helium progresses without the victim experiencing air hunger" (*http://en.wikipedia.org/wiki/Helium*)
11. Apparently ^{3}He is sufficiently abundant in the lunar regolith, where it is produced by cosmic-ray bombardment, that there has been some discussion of mining it for energy production by fusion with deuterium (e.g., *http://www.abc.net.au/news/newsitems/200411/s1252715.htm*)
12. *http://www.time.com/time/magazine/article/0,9171,727672,00.html*
13. The Amarillo plant was recently sold to developers as an industrial park site *http://www.amarillo.com/stories/102007/new_8730998.shtml*
14. named for William Henry Bush, whose father-in-law held the patent on barbed wire, which was tested on Bush's ranch near Amarillo.
15. O'Rourke, P.J., *Parliament of Whores: A Lone Humorist Attempts to Explain the Entire Unites States Government.* Atlantic Montly Press, 1991, p. 99.
16. *http://www.blm.gov/nm/st/en/prog/energy/helium/federal_helium_program.html*
17. "...helium is a by-product of natural gas production, so the behavior of the helium market is dominated by conditions in the natural gas market. This fact has many implications, which are, however, not fully understood, because current economic models for the optimal extraction and storage of nonrenewable by-products are inadequate." - National Academy of Sciences report [6].
18. Anthony Cumbo, Princeton Measurements, pers. comm., 2007.

Heike Kamerlingh Onnes

Born: September 21, 1853, Groningen, Netherlands
Died: February 21, 1926, Leyden, Netherlands

After obtaining his *candidaats* degree at the University of Groningen, Onnes studied for several years under Bunsen and Kirchoff in Heidelberg. He returned to Groningen for his doctorate, with an 1879 thesis on "New Proofs of the Rotation of the Earth" (see p 5 of this issue).
Onnes devoted most of his career to low-temperature physics, and especially to experimental work based on the theories of Van der Waals and Lorentz. His efforts to verify Van der Waals law of corresponding states over a wide range of temperatures in particular led him to new cryogenic frontiers. At Leyden in 1908 he first liquified helium, and succeeded in cooling it to less than 1 K. In 1911 this work led him to the discovery of supeconductivity in pure metals at very low T. He received the 1913 Nobel Prize in Physics "for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium."

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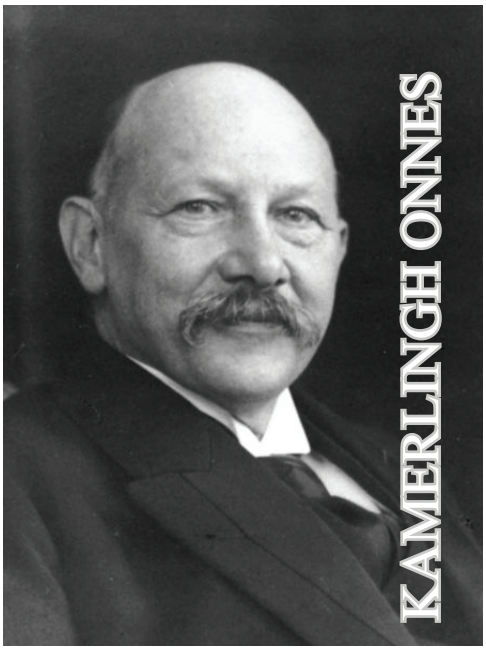

http://nobelprize.org/nobel_prizes/physics/laureates/1913/onnes-bio.html