Hyperpolarisation of Metastable Xe?

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What is Hyperpolarisation ?

Hyperpolarised Noble gases such as ^{3}He and ^{129}Xe created much excitement when it was shown that they could be used to image parts of the body previously off-limits to conventional proton MRI, which relies on high densities of protons to produce images.
By introducing hyperpolarised Noble gases to gas-filled spaces such as the lungs, colon, or sinuses, these areas are "lit-up" by a substance that has an extremely strong MR signature, making imaging possible (fig. 1).

Producing Hyperpolarised Gases

Currently the two methods that are widely used in hyperpolarisation research are;
- Spin Exchange Optical Pumping (**SEOP**)
- Metastable Exchange Optical Pumping (**MEOP**)

SEOP

• Requires the presence of an alkali metal vapour (usually rubidium)
• Gas mixture *optically pumped* with circularly polarised laser light; rubidium vapour acquires high electron spin polarisation
• Collision between electron spin polarised rubidium atoms and unpolarised Noble gas atoms causes *spin exchange*
• Nucleus of Noble gas becomes polarised, and rubidium atom becomes available for optical pumping
✓ SEOP can be applied to a variety of Noble gas isotopes, including ^{3}He and ^{129}Xe
✓ Can be done at atmospheric pressure
× SEOP is ***slow***. Electron spin polarisation of rubidium occurs relatively quickly, however the spin exchange is the rate determining step, and can take several hours

MEOP

✓ **Rapid** process compared to SEOP; high nuclear polarisation can be achieved in minutes, rather than hours
✓ No intermediate alkali metal vapour required
× Has only been successfully applied to ^{3}He thus far
× MEOP is carried out at low pressures; gas required for human lung imaging must therefore be mechanically compressed, or mixed with ^{4}He at atmospheric pressure (both are processes that reduce total polarisation)
• A weak RF discharge is applied to the gas mixture, exciting some ^{3}He into the lowest-lying, long-lived metastable state (^{3}He*)
• The ^{3}He* atoms are optically pumped with circularly polarised laser light, causing certain sub-levels of the metastable state to become depleted i.e. high electron spin polarisation of ^{3}He* atoms
• There is strong hyperfine coupling between the electron and nuclear spins, and a *spin-flip* can occur, causing the nucleus to become polarised. Collisions with ground state atoms cause a metastability exchange, and the end product is a ground state atom with a polarised nucleus and a metastable ^{3}He atom.

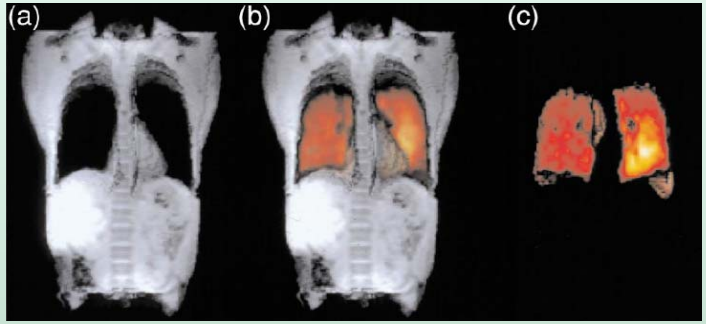

Figure 1; (a) Greyscale ^{1}H abdominal MRI image;
(b) Composite image of images (a) and (c)
(c) False colour ^{129}Xe gas-space image. Reproduced from reference [1]

Helium vs. Xenon

Helium has found wide-spread use amongst the hyperpolarisation community for static lung imaging, due to the large S/N (courtesy of the large magnetogyric ratio of ^{3}He; almost three times that of ^{129}Xe). However, ^{129}Xe is arguably the more versatile gas of the two.

Both gases are chemically inert, but the large electron cloud of xenon is highly polarisable, which gives rise to some unique, useful properties

• Xenon is lipophilic, and is able to interact with various substances, without disrupting them chemically or structurally.

•Specific interactions give rise to specific large chemical shifts, making xenon useful for spectroscopy as well as imaging.

• Xenon is 10 – 100 times more soluble than Helium in various solvents and tissue environments. A consequence of this is that xenon is readily absorbed into the blood stream from the lungs, a process that can be measured by NMR.

• ^{3}He also has the disadvantage of low natural abundance (10^{-4}%, compared to 26% natural abundance ^{129}Xe). ^{3}He is also a politically sensitive substance as the main source of the world's supply come from the decay of tritium, an isotope used in nuclear weapons.

If the methods of producing hyperpolarised ^{129}Xe continue to improve, it seems quite inevitable that the difficulties associated with sourcing ^{3}He (prohibitive price, limited stocks), coupled with the versatility of ^{129}Xe, will lead to a shift toward ^{129}Xe becoming the "gas of choice" in medical and biological applications.

References
[1] B M Goodson, Journ. Mag. Res. **155**, 157 (2002)
[2] V Lefèvre-Seguin and M Leduc, J. Phys. B: Atom. Molec. Phys. **10**, 2157 (1977)
[3] T Hadeishi and Chung-Heng Liu, Phys. Rev. Lett. **17**, 513 (1966)

Metastable Xe?

Hyperpolarisation of ^{129}Xe via a metastable process would be a major breakthrough, especially if the efficiency of the process is similar to that of the metastable ^{3}He process.

Some groups have explored the metastability exchange of xenon using optical pumping, and have failed to achieve a measurable polarisation [2].

There is evidence however that a measurable nuclear polarisation of heavy Noble gas atoms (including xenon) has been achieved via an electron beam method [3].

Metastable Electron Beam Pumping

Metastable exchange of xenon via optical pumping is problematic for the following reason;

• The weak RF discharge that is applied to the gas cell not only creates the desirable metastable states, but higher energy states that are more polarisable are also accessed.

• These states are **radiative**, which means that any angular momentum that is coupled into the system, via incident circularly polarised laser light, will be dissipated before a spin-flip or metastability exchange can occur.

• The technique explored by T. Hadeishi in the 1960s, used a fairly simple electron gun to create the metastable states. A beam of electrons, of well defined energy is passed through the gas contained in the vacuum cell, negating the need for an RF discharge.

•The hypothesis is that metastable states are *selectively* populated, and the problematic high-energy radiative states remain unpopulated, allowing metastability exchange to occur via collisions.

MEBP at Nottingham

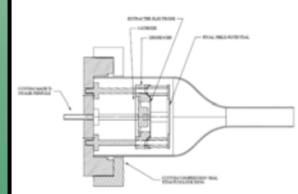

Figure 2; Technical drawing of updated version of Hadeishi's electron gun, custom-built by AP Tech, Portland USA.

Figure 2 shows a technical drawing of the updated version of Hadeishi's electron gun. The gun has a tetrode construction, with adjustable control grids that should allow precise regulation of the electron energy. It is planned to be operational by early 2006. The gun is fabricated from materials far superior to the original, and it is hoped that the performance shall be significantly improved. Initially, some of Hadeishi's experiments with ^{131}Xe and ^{21}Ne will be recreated, in an attempt to corroborate and quantify his findings.