Progress of Hyperpolarized Xenon Production Unit

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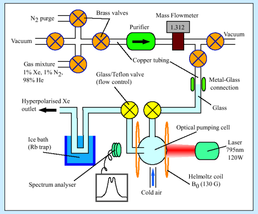
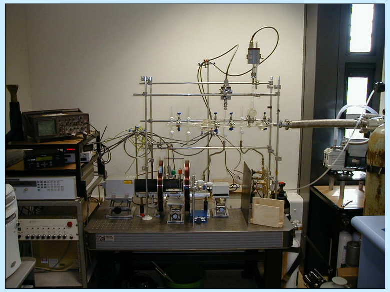
Background

The spin-exchange optical pumping apparatus is based on the original ICR equipment (below left) and is designed to produce hyperpolarized ^{129}Xe in both batch mode, for achieving high levels of polarisation, and flow mode, for producing large quantities of gas.
As part of the BTG consortium the original equipment was reassembled (below right) and a new laser laboratory was established.

We had three initial objectives that needed to be met in upgrading the apparatus:
- Create reliability in the equipment
- Try and remove as much human interaction as possible
- Produce a rig that was more rigid and less fragile, but providing the user with flexibility

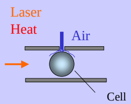


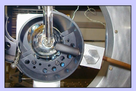


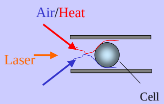
Heating and Cooling System

The laser system uses a 100Watt fiber-coupled diode laser, which produces heating in excess of the requirement for producing polarization. The optical pumping process requires both heating and cooling to maintain a stable temperature of 150°C. Previously cooling was maintained via canisters of air blown on to the cell. Unfortunately this focused the cooling in one place, not providing uniform cooling over the cell and increased the possibility of glass stress. The canisters used were large, but still required replacing every three production cycles.

To overcome these problems a heat gun powered by mains electricity and cooling gun with a variable power supply, created a renewable airflow. Changing the position the heat was delivered created uniform heating and cooling on the cell.

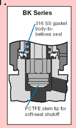


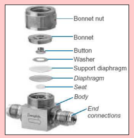




Manual Operating Valves

Original valves on the system comprised brass bellow valves. These are liable to over tightening, and therefore eroding the PCTFE stem over time. Furthermore they are not designed for vacuum systems.
These were replaced with low pressure diaphragm valves which undergo ultra-high purity process cleaning, are helium leak tested to 1x10-9cm3/s and have a working pressure from vacuum up to 17 bar.

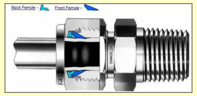


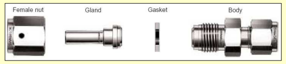


Connections

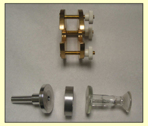
Metal to Metal
To connect the brass valves to the copper tubing, brass gaugeable tube fittings had been used. The problems with these connections were:
- They are not helium leak tested, i.e. not suitable for vacuum.
- Once tightened to make a connection, the copper tubing would become deformed.
- This makes them non-reusable as the brass ferrules deform, which slowly deforms the housing of the brass valves costing a lot to replace.
- When over tightened the brass ferrule and valve housing form a welding between the two metals, which become very difficult to disconnect.
- Over tightening of the brass nut also means that the thread can shear off, becoming damaged and therefore unusable.

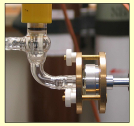
The simplest option was to use SS VCR connections, which provide the high-purity of a metal-to-metal seal, and a leak-tight (4x10-9cm3/s) service from vacuum to positive pressure. The seal of a VCR connection is made when a gasket is compressed between two beads by tightening a male or female nut. These are easily disconnected and reconnected, reconnecting means replacing the copper gasket, which is inexpensive.



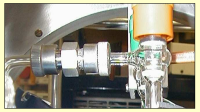


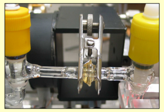
Metal to Glass
Cajon ultra-torr vacuum fittings were used to connect straight sections of glass to copper tubing these are only suitable for a low-pressure system (less than 1.5 bar operating pressure, the working pressure used in the system is 5-6 bar) unless adapted with homemade clamps, which are awkward to use. Therefore an in-house connection was made consisting of a glass flange clamped against a SS flange using a viton o-ring within a centring ring held in place with brass clamps creating a seal. This novel design has been tested from vacuum to 10 bar.





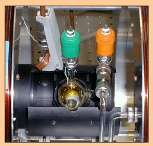
Glass to Glass
Again the ultra-torr vacuum connection was used to hold two straight glass tubings. This was replaced with standard ball and cup fittings. They perform from vacuum to 10 bar, sealed using a ready bought clamp and nut to hold positive pressure, fluorine free hydrocarbon grease is used to create a more effective seal. The clamp also provides rigidity in the glassware, restricting movement.

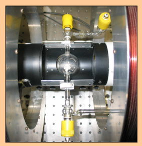




Polarization Cell

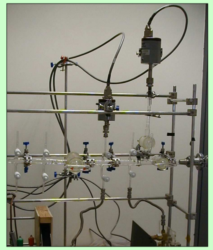
To provide more rigidity within the glassware the cell layout was changed. This meant that every time the cell was placed within the oven it would remain at the same height. PTFE clamps were placed on the arms and tightened when the cell was horizontally centred in position, creating positional reproducibility.





Manifold

The original manifold was constructed of glass, which has a number of drawbacks that needed to be addressed:
- The amount of time taken to degas the grease in the valves and joints.
- Reducing the pressure from 1 atm to less than 1x10-5Torr after cleaning took approx 1 month.
- It was fragile and broken easily under strain.
- Connections were ultra-torr cajon fitting, which could not exceed an overpressure of 1.5 bar, and there is a high risk of the manifold exploding.



The glass manifold was replaced with connected stainless steel (SS). This provided:
- A manufacture quoted helium leak test rate of 4x10-9cm3/s.
- Over pressure of 200bar.
- Connections made via copper metal gaskets (VCR) simple to connect and disconnect
- No need for grease to connect joints or lubricate valves
- Possible to use heating element to speed up the degassing phase, which now only takes a few days, if system has been exposed to atmosphere for long periods of time
- A manifold that is reliable, and rigid, but provides flexibility of use.

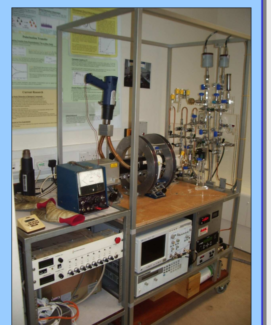
LN2 Xe Collector

The collector is designed to provide stability as well as manoeuvrability. This is achieved using a nylon holder to cradle the distillator; the holders' height can be varied within the magnet and the LN2 dewar. This height is also variable in relation to the table it sits on.

New Portable System

There were two main reasons to create a new platform for the hyperpolarized rig:
- Initial attempts at NMR spectroscopy on rig were unsuccessful, this was due to magnetic susceptibility from the optical bench, and therefore a non-magnetic replacement was needed.
- There was a possibility that the laser lab would have to be relocated when the new MRI scanner was installed, and so simpler to move all equipment in one go

The portable unit holds:
- All the glassware
- Stainless Steel Manifold
- All electrical power supplies and equipment
- 5 gas canisters for variability of use
- The laser, with the power unit on another moveable unit



Acknowledgements

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