APPARATUS AND METHOD FOR POLARIZING POLARIZABLE NUCLEAR SPECIES

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a divisional of Ser. No. 09/904,294 filed Jul. 12, 2001 now U.S. Pat. No. 6,949,169, which claims the benefit of U.S. Provisional Application Ser. No. 60/217,569 filed on Jul. 12, 2000, both of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention is in the field of hyperpolarizing polarizable nuclear species, such as xenon.

BACKGROUND OF THE INVENTION

Nuclear magnetic resonance (NMR) is a phenomenon, which can be induced through the application of energy against an atomic nucleus being held in a magnetic field. The nucleus, if it has a magnetic moment, can be aligned within an externally applied magnetic field. This alignment can then be transiently disturbed by application of a short burst of radio frequency energy to the system. The resulting disturbance of the nucleus manifests as a measurable resonance or wobble of the nucleus relative to the external field.

For any nucleus to interact with an external field, however, the nucleus must have a magnetic moment, i.e., non-zero spin. Experimental nuclear magnetic resonance techniques are, therefore, limited to study of those target samples, which include a significant proportion of nuclei exhibiting non-zero spin. Certain noble gases, including xenon, are in principle suited to study via NMR. However, the low relative natural abundance of these isotopes, their small magnetic moments, and other physical factors have made NMR study of these nuclei difficult if not impossible to accomplish.

Existing technology for polarizing xenon, developed primarily at Princeton, is based on earlier work on nuclear polarized 3He gas targets for nuclear physics. The key component of the system is the polarizing chamber where the 3He gas is heated, saturated with rubidium, an alkali metal vapor, and illuminated with laser light. In these devices, a closed cell of 3He gas, rubidium, and nitrogen is maintained at a uniform high temperature to achieve an appropriate rubidium density. A laser illuminates the cell with circularly polarized light at the resonant absorption line of the rubidium, polarizing the rubidium electrons. Spin exchange occurs with the 3He gas nucleus, leading to an accumulation of nuclear polarization. 3He gas atoms diffuse throughout the cell.

Xenon polarization proceeds by a similar mechanism. Circularly polarized laser light polarizes rubidium atoms, which in turn transfer their polarization to the xenon nucleus. Xenon, however, has a large depolarization effect on rubidium. Therefore the partial pressure of xenon must be kept low. Diode lasers, which are used to illuminate the gas mixture, have a large linewidth. In order to more efficiently absorb more of this laser light, the rubidium should be in a high-pressure gas to pressure-broaden the absorption line. Princeton researchers use a high-pressure buffer gas of helium. They slowly flow a mixture of xenon, nitrogen, and helium through the polarizing cell. A sufficient quantity of rubidium is available in the polarizing cell. The unpolarized gas slowly enters this chamber and diffusively mixes with rubidium vapor and partially polarized gas already in the chamber. Rubidium condenses as the gas exits and cools down.

The use of a high-pressure buffer gas, such as helium, causes pressure broadening of the absorption spectrum of the rubidium, allowing greater extraction of laser power in a compact pumping cell with low rubidium density. Operation at high-pressure, however, changes the dominant mechanism for transferring polarization from the rubidium to the xenon. At high pressures the dominant mechanism is the two-body interaction. At low pressures, the mechanism mediated by three-body formation of molecules dominates which is considerably more efficient. Consequently, the improvement in polarization achieved by the gain in laser efficiency is partially offset by a reduction in rubidium-xenon polarization transfer.

Existing polarization techniques also use a gas mixture dominated by helium at high pressure. The high pressure of helium broadens the absorption linewidth of the rubidium, allowing it to usefully absorb more of the linewidth of the diode laser. If they reduce the pressure, they would not absorb as much light in their short polarizing cells. If they lengthened their cells using their diffusively mixed process, they would mix gas from regions with an even greater range of polarization rates. If the existing process could be performed effectively at low pressure, however, the polarization system would be capable of taking advantage of the higher efficiently molecular formation physics.

Existing polarization methods cannot efficiently use the full polarizing power of the laser beam. The gas mixture attenuates the laser light. Consequently, the region of the polarizing cell farthest from the laser will only achieve low rubidium polarization if the cell is long. Since the gas in the polarization cell is diffusively mixed, the xenon will achieve an average polarization that is influenced by both the high rubidium polarization and the low rubidium polarization. To minimize the region of low rubidium polarization, the laser must exit the polarizing cell after using only a portion of its polarizing power.

SUMMARY OF THE INVENTION

The present invention results from the realization that by using a longer than standard polarizing cell and flow within the cell dominated by laminar displacement, polarizing polarizable nuclear species can be accomplished at low pressure with high temperature and high velocity, thereby taking advantage of the higher efficiency molecular formation physics.

It is therefore an object of this invention to dominate the flow through the cell by laminar displacement.

It is a further object of this invention to polarize polarizable nuclear species with high velocity.

It is a further object of this invention to increase efficient use of resonant light.

It is a further object of this invention to polarize polarizable nuclear species with high temperature.

It is therefore an object of this invention to polarize polarizable nuclear species at low pressure.

BRIEF DESCRIPTION OF THE INVENTION

The novel features believed characteristic of the invention are set forth in the claims. The invention itself however, as well as other features and advantages thereof, will be best