United States Patent

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[73] Assignee **The United States of America as represented by the United States Atomic Energy Commission**

[54] **METHOD FOR PRODUCING POLARIZED ATOMS**
6 Claims, 1 Drawing Fig.

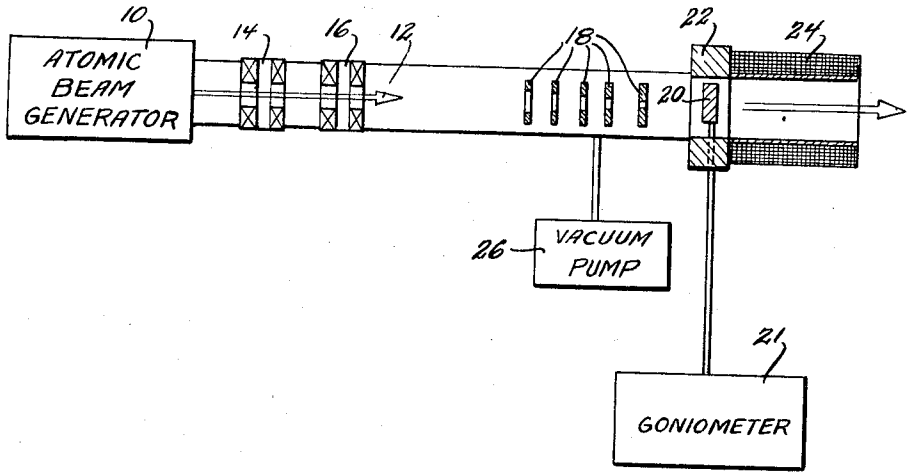
[52] **U.S. Cl.** **250/84,** 313/63
[51] **Int. Cl.** **H01j 37/00**
[50] **Field of Search** 250/84; 313/63, 230

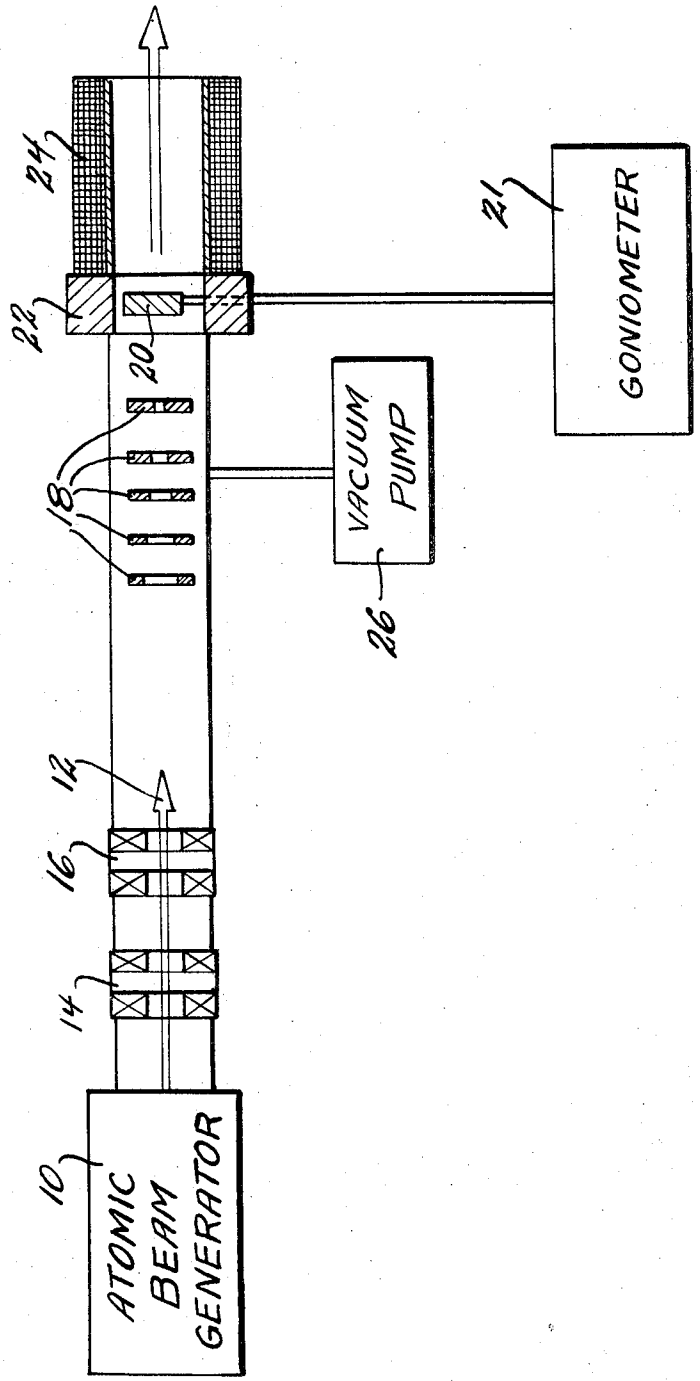
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ABSTRACT: A polarized beam of atoms is generated by passing in a partial vacuum a collimated atomic beam through a magnetically saturated monocrystalline material parallel to a lattice channel of said foil. The monocrystalline material effects a charge-transfer reaction with the atomic beam to produce a polarized atomic beam, the nuclei of which are subsequently polarized by hyperfine interaction in a weak external magnetic dipole field.





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METHOD FOR PRODUCING POLARIZED ATOMS

CONTRACTUAL ORIGIN OF THE INVENTION

The invention described herein was made in the course of, or under, a contract with the UNITED STATES ATOMIC ENERGY COMMISSION.

BACKGROUND OF THE INVENTION

This invention relates to methods for producing polarized atomic beams.

Polarized atoms are generally used in particle accelerators to study nuclear reactions. Presently, polarized atoms are produced by an atomic beam method using separation magnets and RF transitions, as disclosed by W. Haeberli, "Sources of Polarized Ions," Annual Review of Nuclear Science, Vol. 17, 1967. This method of producing polarized atoms is expensive and also requires relatively complex equipment.

It is therefore one object of the present invention to provide an improved method for producing polarized atoms.

It is another object of the present invention to provide a relatively inexpensive method for producing polarized atoms.

It is still another object of the present invention to provide a simpler method than heretofore for producing polarized atoms.

Other objects of the present invention will become more apparent as the detailed description proceeds.

SUMMARY OF THE INVENTION

In general, a beam of atoms is polarized according to the method of the present invention by magnetically saturating a monocrystalline material, generating a partial vacuum and transmitting in said partial vacuum said atomic beam through the material in a direction parallel to a lattice channel in said material, the monocrystalline material polarizing the atomic beam to provide a beam of polarized atoms.

BRIEF DESCRIPTION OF THE DRAWING

Further understanding of the present invention may best be obtained from consideration of the drawing wherein is shown in schematic form an apparatus for the practice of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the method of the present invention a beam of atoms (positive ions, negative ions or neutral atoms) is generated and highly collimated to impinge in a partial vacuum on a surface of a magnetically saturated monocrystalline material in a direction parallel to a lattice channel in said material. The atomic beam, in passing through the magnetically saturated monocrystalline material along a lattice channel thereof, undergoes a charge transfer reaction therewith to acquire polarized electrons, whereby the beam emerging from the monocrystalline material is a polarized beam of atoms. Subsequent to passage through the monocrystalline material the beam is passed through a weak magnetic field having the same directional sense as the direction of the field of magnetization of the monocrystalline material. This weak magnetic field extends in the direction of transmission of the atomic beam a distance sufficient to provide a transit time for the atomic beam greater than the Lamor precession time of the nuclear magnetic moment of the nucleus of the atomic beam thereby effecting nuclear polarization of the beam by hyperfine interaction. Thus, in the weak magnetic field nuclear polarization by hyperfine interaction between the magnetic moment of a captured polarized electron and the nuclear magnetic moment of the associated nucleus of the atom is effected.

For the practice of the present invention, a lattice channel in the monocrystalline material includes the planar channels and axial channels of the material as exemplified by the [110], [100], [111], or [112] axial channels and (110), (100), (111), or (112) planar channels of a face centered cubic monocrystalline material. It will be appreciated that similar

channels exist for other monocrystalline materials having different crystallographic structures such as body centered or hexagonal close-packed materials and the method of the present invention is equally applicable thereto.

Further understanding of the method of the present invention may best be obtained by reference to the attached FIG. wherein is shown an apparatus for the accomplishment of the method. A beam generator **10** generates a beam of atoms (positive ions) **12** which is passed through a pair of quadrupole magnets **14** and **16**. Subsequent to the quadrupole magnets, the beam **12** is passed through the successively diametrically decreasing apertures of collimators **18** to strike a surface of a ferromagnetic monocrystalline material **20** parallel to a lattice channel thereof. The monocrystalline material **20** is mounted on a goniometer **21** to enable adjustable motion of the material to align the lattice channel direction relative to the generated beam **12**. A magnet **22** provides a DC magnetic field through the monocrystalline material normal to the direction of said atomic beam sufficient to effect magnetic saturation thereof. Subsequent to the monocrystalline material is a second magnet **24** mounted to provide a weak homogeneous magnetic dipole field in the same directional sense as the direction of the field of magnetization passing through the monocrystalline material **20**.

The aforedescribed structure is housed so that the beam generation and transmission through the collimator and monocrystalline material **20** and the magnetic field from magnet **24** is accomplished in a partial vacuum of approximately 2×10^{-8} torr maintained by a pump **26**.

In operation the beam **12** emerging from the generator **10** is acted upon by the quadrupole fields of magnets **14** and **16** to reduce the beam diameter. The apertures in the collimators **18** are aligned in decreasing size arrangement to provide a highly collimated beam **12** of approximately 1 mm. diameter at the surface of the monocrystalline material **20**. As previously stated, the monocrystalline material **20** is mounted such that the highly collimated beam **12** strikes a surface of the material parallel to a lattice channel in the material. With the monocrystalline material **20** in a state of magnetic saturation, the collimated beam **12**, passing therethrough along a lattice channel of the material captures polarized electrons from the material **20** in a charge-transfer reaction to provide an emerging atomic beam which is polarized. The weak homogeneous magnetic dipole field generated by magnet **24** in the same directional sense as the direction of the field of magnetization from magnet **22** permits nuclear polarization by hyperfine interaction between the magnetic moment of the captured polarized electron from the material **20** and the nuclear magnetic moment of the atom in the beam **12** by keeping the axis of polarization unperturbed. It will be appreciated that for this nuclear polarization by hyperfine interaction that the transit time for the atomic beam in the weak magnetic dipole field is greater than the Lamor precession time of the nuclear magnetic moment of the nuclei of the atomic beam. Thus, at the output of the weak magnetic dipole field generated by the magnet **24** a beam of nuclear-polarized atoms is produced.

With a 2 MEV Van de Graff accelerator operating to generate a deuteron beam emerging from the monocrystalline material **20** at particular mean energies ranging from 110,000 to 150,000 electron volts, and the deuteron beam sized to a collimated beam having a diameter of 1 mm. and maximum half-angle of divergence less than 0.01° at a low index plane of the material, a nuclear-polarized beam of neutral hydrogen atoms was effected having a tensor polarization of $P_{zz}=-0.32$. This tensor polarization was obtained using monocrystalline ferromagnetic material such as nickel having a thickness of 2 microns in the direction of propagation of the beam. The atomic beam was propagated to be incident parallel within 0.10° to the [110] axial channel of the ferromagnetic material. The magnetic saturation of the ferromagnetic material was effected in a magnetic field of 12 kilogauss which was reduced to a value of 160 gauss to maintain magnetization and the weak field generated by the magnet **24** was approximately 10

gauss. It will be appreciated that the method of the present invention may be utilized with atomic beams other than deuterons. For example, it is applicable to atoms having low atomic numbers, such as protons, tritons, helium and lithium, and may be used to produce polarized atoms of these substances. It will be further appreciated that the method of the present invention may produce nuclear-polarized atoms which are either neutral, negative or positive. For example, where positive hydrogen atoms are generated to impinge on the low index surface of the monocrystalline material, polarized neutral hydrogen atoms are produced at the output of the magnetic field of magnet 24. A transfer of the polarized neutral hydrogen atoms to positive or negative polarized hydrogen atoms may then be effected by passing the beam through a lattice channel of a monocrystalline charge-transfer foil.

The method of the present invention is effective only with monocrystalline materials and as such the atomic beam must impinge parallel to a lattice channel as hereinbefore described. While as previously set forth the present method operates satisfactorily with any ferromagnetic monocrystalline material, the method should operate satisfactorily with paramagnetic monocrystalline materials having a high magnetic susceptibility, that is, paramagnetic monocrystalline materials having a Heisenberg's exchange integral ratio of the average lattice distance to the lattice atom diameter greater than 1.5. This includes such monocrystalline paramagnetic materials as gadolinium, dysprosium, holmium and terbium.

For maximum polarization according to the method of the present invention, the atomic beam should be collimated so that it has a maximum half-angle of divergence of 0.01° at a low index plane of the material. As the angle of divergence increases, the efficiency of the method falls off. It will be appreciated that for the practice of the present invention the energy at which the beam is generated and transmitted through the material and the thickness of the material relative the direction of propagation of the atomic beam are such as to effect the charge-transfer reaction of capturing by the atomic beam of the polarized electron from the monocrystalline material and that the present invention is not limited to the aforedescribed thickness and beam energy.

Persons skilled in the art will, of course, readily adapt the general teachings of the invention to embodiments far different from the embodiments illustrated. Accordingly, the scope of the protection afforded the invention should not be limited to the particular embodiment illustrated in the drawing and described above but should be determined only in accordance with the appended claims.

I claim:

1. A method of polarizing a beam of atoms comprising magnetically saturating a monocrystalline material, generating a partial vacuum, and transmitting in said partial vacuum said atomic beam through said material in a direction parallel to a lattice channel in said material and normal to the direction of magnetic saturation, said monocrystalline material polarizing said atomic beam by effecting a charge-transfer reaction therewith.

2. The method according to claim 1 wherein said atomic beam is collimated to provide a maximum half-angle of divergence from the axis of transmission at the surface of said monocrystalline material of 0.01°.

3. The method according to claim 1 wherein said monocrystalline material is ferromagnetic.

4. The method according to claim 1 further including generating a magnetic field, and passing said atomic beam through said magnetic field after transmission through said monocrystalline material a distance in the direction of transmission of said atomic beam sufficient to provide a transit time therefor greater than the Lamor precession time of the nuclear magnetic moment of the nuclei of the atomic beam to effect nuclear polarization of said beam by hyperfine interaction.

5. The method according to claim 4 wherein said magnetic field is generated in the same directional sense as the magnetic saturation of said monocrystalline material.

6. A method for generating a polarized beam of atoms comprising magnetically saturating a monocrystalline material, generating a partial vacuum, generating a beam of atoms, collimating said atomic beam, transmitting said collimated beam of atoms in said partial vacuum through said material parallel to a lattice channel in said material and normal to the direction of magnetic saturation, said monocrystalline material effecting a charge-transfer reaction with said atomic beam to produce a polarized atomic beam, and passing said polarized atomic beam through a magnetic field to polarize the nuclei thereof by hyperfine interaction.