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Atomic Beam Source of Polarized Electrons

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At least four methods of obtaining polarized electrons have been investigated recently: 1) photoelectric emission from a ferromagnet, 2) field emission from a ferromagnet, 3) optical pumping techniques, 4) atomic beam techniques.

Measurements of the polarizations of photoelectrons from a single crystal of nickel(1) and from thin films of iron, nickel and cobalt(2) by use of Mott scattering have shown that the polarizations are zero within the experimental errors of 3% to 5%. Similarly, the polarization of field-emitted electrons from magnetized iron has been found(3,4) to be less than 0.2%. Optical pumping techniques for producing polarized electrons, which are being studied in several laboratories, are based on the possibilities of producing polarized alkali atoms by use of polarized resonance radiation(5) and of producing polarized electrons in exchange collisions of electrons with polarized alkali atoms.(6)

Polarized electrons have been produced successfully(7) by an atomic beam method in which polarized alkali atoms are selected by deflection in an inhomogeneous magnetic field(8) and the polarized electrons are then obtained by photoionization of the polarized atoms. The energy level diagram(9) of the hyperfine structure levels of the ground state of potassium in a magnetic field is shown in figure 1. By deflection in a strong inhomogeneous magnetic field atoms in states with $m_J = +1/2$ (m_J = magnetic quantum number for electron spin) can be separated from atoms in states with $m_J = -1/2$. If the magnetic field is sufficiently strong in the region where photoionization occurs, the photoelectrons will have a large polarization since the photoionization process is predominantly an electric dipole transition. The electronic polarization for potassium of the group of states having $m_J = +1/2$ in a strong magnetic field is shown as a function of magnetic field in figure 2.

The apparatus constructed at Yale for the production and anlysis of a source of polarized electrons is shown schematically in figure 3. The oven has 30 circular apertures each 0.025 cm in diameter and hence a total aperture of 0.014 cm^2. The inhomogeneous magnetic field is provided by a six-pole permanent magnet (see figure 4) with a pole tip field of 9000 gauss. In an idealized six-pole configuration the magnitude of the magnetic field H is given by:(9)

$$H = H_o \left(\frac{r}{a} \right)^2, \qquad \text{independent of } \phi$$

in which H_o is the pole tip field, a is the radial coordinate of the pole tip, and (r,ϕ) are cylindrical coordinates. The force on a magnetic dipole moment is

$$\vec{F} = \frac{2H_o}{a^2} \mu \vec{r}$$ [redacted]

in which μ is the component of the magnetic dipole moment in the radial direction. If μ is negative, the particle will experience a force towards the axis and will execute simple harmonic motion with a wavelength

$$\lambda = \sqrt{2}\,\pi\, a\, v \sqrt{\frac{m}{\mu_o H_o}}$$

in which v is the velocity of the particle, m is the mass, and μ_o is the Bohr magneton. If μ is positive, the particle will be deflected away from the axis. Particles with negative μ ($m_J = +1/2$) are focussed into the photoionization region. An axial magnetic field of about 400 gauss is applied in the photoionization region by Helmholtz coils exterior to the vacuum system. Ultraviolet light is focussed onto the atomic beam and the photoelectrons are extracted from the photoionization region, which is at a potential of -120 kv, and then accelerated to ground potential. Analysis of the polarization is to be accomplished by Mott scattering after the polarization has been changed from longitudinal to transverse by deflection in an electric field.[10]

The design characteristics of the polarized electron source with potassium atoms are listed in Table I. The apparatus has been constructed and is presently under test.

TABLE I

Design Characteristics of Potassium Polarized Electron Source.

Flux from oven = 4×10^{18} atoms/sec

Fraction accepted by magnet = 5×10^{-4}

Fraction in $m_J = +1/2$ states = 0.5

Fraction transmitted by magnet = 0.8

Polarized atoms into ionizer = 8×10^{14}/sec

Ionization efficiency = 3×10^{-4} electrons/atom

Accelerated electron beam = 2×10^{11}/sec or 3×10^{-8} amp

Electron polarization = 90%

The choice of alkali atom is determined primarily by its photoionization cross section (see figure 5) and by its hyperfine structure interval. (See Table II) From figure 5 it is seen that lithium has a particularly large photoionization cross section, and xenon light sources in the appropriate wavelength range are now available. Furthermore the hfs interval $\Delta\nu$ for Li^7 is 804 Mc/s so that the static magnetic field required in the photoionization region in order to obtain an electron polarization of 90% is only about 500 gauss. Hence lithium may be the most favorable atom to use for a polarized electron source. Although cesium has a reasonably large photoionization cross section over a useful wavelength range, its hfs interval is so large that an inconveniently large static magnetic field is required in the photoionization region. Our initial studies are being done with potassium because the potassium atom is easily detected with a hot wire surface ionization detector (whereas detection of lithium requires oxygenation of the wire) and because a mercury light source can be used for photoionization of potassium.

TABLE II

Hyperfine Structure Intervals

Alkali Atom	Isotopic Abundance (percentage)	HFS Interval, $\Delta\nu$ (in Mc/s)
Li^6	7.5	228
Li^7	92.5	804
Na^{23}	100	1772
K^{39}	93	462
K^{41}	7	254
Rb^{85}	73	3036
Rb^{87}	27	6835
Cs^{133}	100	9193

Polarized electrons could be used to study the electron spin dependence of atomic collisions cross sections in a crossed electron-atom beam experiment.