MEASUREMENT OF THE POLARIZATION OF PHOTOELECTRONS FROM FERROMAGNETS

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The polarization of electrons ejected from ferromagnetic substances of the iron group by photons having energies up to 1 eV above the work function is measured by observing Mott scattering. The observed polarization is $<0.2\%$. Possible depolarization mechanisms are discussed qualitatively as well as possible means of observing the effect (by increasing the photon energy, and by investigating rare-earth ferromagnets).

IT was suggested in 1930 that polarized electron beams might be produced by extracting the electrons in some way from ferromagnetic substances.[1] Since then several unsuccessful attempts have been made (reviewed in[2]); only very recently ~8% polarization of field-emission electrons from gadolinium was achieved.[3] In the present work we observed the polarization of photoelectrons emitted by ferromagnets.

Our apparatus consists of a pumping system, a system for illuminating and reversing the magnetization of a ferromagnetic sample, an electron-optical system for focusing and accelerating electrons to 120 kV, and a polarization detector based on Mott scattering. Our basic material was polycrystalline Permendur (50% Co, 50% Fe: $B_S \sim 21$ kilogauss) cut in the form of a rectangular frame around which a magnetizing coil is wound. Following suitable heat treatment the saturation induction is attained in a ~10-Oe field. Preliminary experiments showed that it was advisable to work with the residual induction (~11 kilogauss), which is accompanied by practically no instrumental asymmetry resulting from stray magnetic fields.

The surface magnetization of the sample was monitored by magnetooptic measurements based on the equatorial Kerr effect.[4] The surface was weakly etched. The surface layer was saturated in a 30-Oe field; the residual magnetization then comprised about one-half of this surface-layer saturation magnetization. Unfortunately, these measurements cannot yield the absolute magnetization nor detailed information regarding the surface spin state. Reversal of the magnetization was accomplished using 20-A current pulses of 1 μsec duration; this corresponds to a field of about 450 Oe on the surface.

Figure 1 shows the arrangement used for illumination. The lamp, with a quartz window that is transparent up to 150 nm, emits the hydrogen continuum. For our measurements we used filters consisting of distilled water and acetic acid, in different proportions, contained in a quartz vessel. The transmission curves are shown in Fig. 2. With these filters we were able to vary the light frequency limit within a ~1 eV range.

The accelerating system was taken from a 1.5 BPV 2-400 x-ray tube. The electron-optical system enlarges the sample image about 1.5 times on the scattering target, while the background becomes one order of magnitude weaker. A diaphragm positioned directly in front of the target transmits only electrons from the sample.

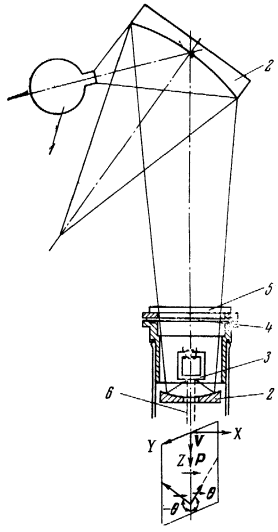

FIG. 1. Scheme for illuminating the sample. 1 – DVS-200 lamp, 2 – Dural mirror, 3 – sample, 4 – quartz window of apparatus, 5 – filter, 6 – electron beam.

The polarization analyzer is a Mott detector that consists of a scattering target and scintillation counters.[5] As scattering targets we used gold 100 $\mu g/cm^2$ thick and copper 120 $\mu g/cm^2$ thick; these thicknesses are accurate to within 10%. The target metals were deposited on a collodion substrate 20–40 $\mu g/cm^2$ thick. The target was "seen" by counters within a solid angle of 1.5×10^{-3} sr; the scattering angle was $\theta = 120^\circ$.

The apparatus was evacuated via the scattering chamber by means of an N-5 oil diffusion pump. During the measurements the pressure around the sample was about 10^{-6} Torr.

We used a modulation technique, measuring the change of count asymmetry from a given target upon reversing the magnetization. The asymmetry (using the coordinate system shown in Fig. 1) is given by the conventional formula

$$\delta = \frac{N(\theta) - N(-\theta)}{N(\theta) + N(-\theta)},$$

where $N(\theta)$ and $N(-\theta)$ are the counting rates in the different channels of the Mott detector. We assumed that for a given magnetization $M_K > 0$ the asymmetry

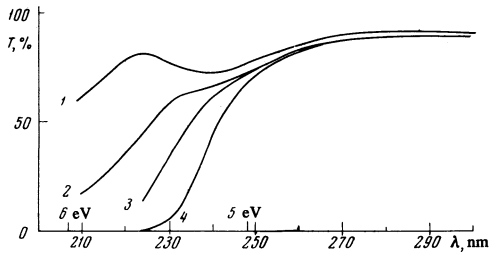

FIG. 2. Filter transmission as a function of wavelength. Composition of filters: 1 – 0, 2 – 1.0, 3 – 5.0, 4 – 10 g acetic acid in 1 liter of water.

can be represented by

$$\delta_+ = \delta_{eff} + \delta'_{s.f.} + \delta_{instr} \quad (1)$$

Correspondingly, for the opposite sign of magnetization we have

$$\delta_- = -\delta_{eff} + \delta''_{s.f.} + \delta_{instr}. \quad (2)$$

Here δ_{eff} is the asymmetry resulting from beam polarization. We know[2] that $\delta_{eff} = PS$, where P is the degree of electron polarization and S is a function of the electron energy, scattering angle, and scattering target. For our case $S_{AU} = -0.380$[6] and $S_{CU} = -0.090$.[7] Furthermore, $\delta'_{s.f}$ and $\delta''_{s.f}$ are the asymmetries induced by the stray magnetic fields, which do not depend on the target but are generally different for opposite signs of the magnetization; δ_{instr} is the asymmetry resulting from inaccurate preparation of the apparatus and from nonidentical counting channels.

From (1) and (2) for the gold and copper targets we obtain the polarization:

$$P = 1{,}72[(\delta_{+Au} - \delta_{-Au}) - (\delta_{+Cu} - \delta_{-Cu})]. \quad (3)$$

In our experiments δ is about 6–8%.

The table gives the results obtained with Permendur. The counting rate without a filter reached 5×10^3 pulses/sec with a background below 10 pulses/sec. The table shows that the measured polarization was $< 0.2\%$. Similar results were obtained without a filter for polycrystalline samples of Ni and the ferrite $Co_{0.02}Ni_{0.52}Zn_{0.26}Cr_{0.2}Fe_2O_4$.

No. of filter	Photocurrent in target, 10^{-12} A	P, %
Without filter	280	0,09±0,05
1	120	0,08±0,05
2	39	0,14±0,05
3	7,5	0,08±0,11
4	3	0,28±0,14

We have analyzed the possible causes of the practical absence of photoelectron polarization.

1. The surface conditions of our samples were very unsatisfactory considering the present-day status of vacuum technology. However, for our exploratory work we considered it feasible to confine ourselves to oil-vapor pumping, because we are still far from knowing the depth at which photoelectron emission can occur.[8] Therefore the (presumably) multilayered surface film of impurities that was inevitably present under our experimental conditions would perhaps not affect the polarization of electrons that are emitted from a depth of a few atomic layers. We tested for the possible accumulation of thicker layers on the sample surface under the influence of light and ion bombardment. For this purpose we used the silvered surface of a quartz resonator as a photocathode and observed changes in its frequency by the radio balance method.[9] We used 16-Mc AT-cut resonators with 580 Hz-cm^2/μg sensitivity, and found that the frequency shift did not exceed 20 Hz after several hours. A multilayered substance (10^{14} atoms/cm^2) having the density of water would produce a shift of 50-Hz.

2. Depolarization of the photoelectrons while passing through the metal could hardly produce a significantly lower degree of polarization.[20] Following Dayhoff's work[10] we measured the line width of ferromagnetic resonance (FMR) in our Permendur samples, and obtained 4 kOe in the centimeter wavelength region, which corresponds to 5×10^{-11} sec as the time required for spin reversal. Recent calculations have given $\tau_{ph} \sim 10^{-13}$ sec as the time elapsing during the photoemission process in metals.[11] We thus have reason to believe that no essential degree of depolarization occurred in our experiments. An indirect confirmation is also found in experiments on the annihilation of polarized positrons in ferromagnets.[12] We propose to subsequently select samples with the narrowest possible FMR line.

We note that by utilizing FMR we are also enabled, at least in principle, to monitor the spin state on the surface.[13]

3. We have the least amount of information about the depolarization of electrons which are being excited. It is certain[2] that when a photon ejects an electron from an isolated atom the spin of the electron is not affected. In a metal, however, the situation is considerably more complicated as a result of collective effects.

4. Theoretical calculations of the electron state density distribution in ferromagnets of the iron group[14] indicate that polarization amounting to several times ten per cent can be attained near the Fermi energy. However, recent experiments[15] on the photoelectron energy distribution in these metals are in disagreement with these calculations and suggest that the polarized electrons mainly possess energy that is about 5 eV below the Fermi energy. In the present work we went at most 1 eV below the Fermi energy.

We plan future experiments using photons up to 10 eV. It would also be interesting to investigate the photoelectric effect in rare-earth ferromagnets such as gadolinium, for which the polarization of field-emission electrons has already been achieved.

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