Preface

The phenomena of interference, diffraction and refraction of light are well known even to lycee and college students. A great variety of their applications is described in school and university manuals and popular science books [Born and Wolf (1965); Purcell (1985); Crawford (1968); Wichman (1967); Agranovich and Gartstein (2006)]. Centuries–long argument about the nature of light: whether light is a wave or a particle, finally led to the creation of quantum mechanics and extension of the wave conception to the behavior of any particles of matter. As a result, optical concepts and notions were also introduced for describing interaction of particles with matter, nuclei, and one another [Landau and Lifshitz (1977); Fermi (1950); Feynman *et al.* (1965)]. In particular, widely used nowadays is diffraction of electrons and neutrons by crystals, which are in fact natural diffraction gratings. Neutron interferometers were designed [Greenberger and Overhauser (1979)]. It was found out that scattering of particles by nuclei (and by one another) is in many cases similar to scattering of light by a drop of water (the optical model of the nucleus).

A study of interaction between light and matter has shown that besides frequency and propagation direction, light waves are characterized by polarization.

The first experiment, which observed a phenomenon caused by the polarization of light, was carried out in 1669 by E. Bartholin, who discovered the double refraction of a light ray by Iceland spar (calcite). Today it is common knowledge that in the birefringence effect, the stationary states of light in a medium are the states with linear polarization parallel or perpendicular to the optic axis of a crystal. These states have different refractive indices and move at different velocities in a crystal. As a result, for example, circularly polarized light in crystals turns into linearly polarized and vice versa [Born and Wolf (1965)].

Another series of experiments was performed by D.F. Arago in 1811 and J.B. Biot in 1812. They discovered the phenomenon of optical activity, in which the light polarization plane rotates as the light passes through a medium. In 1817, A. Fresnel established that in an optically active medium rotating the polarization plane, the stationary states are the waves with right-hand and left-hand circular polarizations, which, as he found out in 1823, move in a medium at different velocities (i.e., propagate with different refractive indices), thus causing the polarization plane to rotate. Let us also recall the effect of light polarization plane rotation in matter placed in a magnetic field, which was discovered by Faraday, and the birefringence effect in matter placed in an electric field (the Kerr effect).

The above-mentioned phenomena and various other effects caused by the presence of polarization of light and optical anisotropy of matter have become the subjects of intensive studies and found wide applications. The microscopic mechanism leading to the appearance of optical anisotropy of matter is, in the final analysis, due to the dependence of the process of electromagnetic wave scattering by an atom (or molecule) on the wave polarization (i.e., on the photon spin) and to bounds imposed on electrons in atoms and molecules. Beyond the optical spectrum, when the photon frequency appears to be much greater than the characteristic atomic frequencies, such bounds become negligible, and the electrons can be treated as free electrons. As a result, the effects caused by optical anisotropy of matter, which are studied in optics, rapidly diminish, becoming practically unobservable when the wavelengths are smaller than 10^{-8} cm.

Moreover, there is a widespread belief that it is only possible to speak of the refraction of light and to use the concept of the refraction index of light in matter because the wavelength of light ($\lambda \approx 10^{-4}$ cm) is much greater than the distance between the atoms of matter R_a ($R_a \approx 10^{-8}$ cm) since only in this case ($\lambda \gg R_a$) matter may be treated as a certain continuous medium. As a consequence, in a short-wave spectral range where the photon wavelength is much smaller than the distance between the atoms of matter, the effects similar to the Faraday effects and birefringence, which are due to refraction, should not occur. However, such a conclusion turned out to be incorrect. The existence of the refraction phenomena does not appear to be associated with the relation between the wavelength λ and the distance between atoms (between scatterers). Even at high photon energies when the wavelength is much smaller than R_a, the effects due to refraction of waves in matter can be quite appreciable. Thus, for example, when a beam of linearly polarized γ-quanta with the energies greater than tens of kiloelectronvolts (wavelengths smaller than 10^{-9} cm) passes through matter with polarized electrons, there appears rotation of the polarization plane of γ-quanta, which is kinematically analogous to the Faraday effect ([Baryshevskii and Lyuboshitz (1965); Baryshevskii *et al.* (1972); Lobashev *et al.* (1971); Lobashev *et al.* (1975); Bock and Luksch (1971)]). Moreover, with the growth of the energy of γ-quantum (the decrease in the γ-quantum wavelength) the effect increases, attaining its maximum in the megaelectronvolt energy range. Unlike the Faraday effect, which is due to the bounds imposed on electrons in atoms, for γ-quanta electrons may be treated as free electrons. The effect of polarization plane rotation in this case is due to the quantum–electrodynamic radiative corrections to the process of scattering of γ-quanta by an electron, which are lacking in classical electrodynamics.

Analogously, the propagation in matter of the de Broglie waves, which describe motion of massive particles, can be characterized by the refractive index [Goldberger and Watson (1984); Fermi (1950)]. In this case, the refractive index also characterizes particle motion in matter, even at high energies, for which the de Broglie wavelength $\hbar/mv$ (m is the particle mass, v is its velocity, in the case of relativistic velocities m stands for the relativistic mass $m\gamma$, γ is the Lorentz factor) is small in comparison with the distance between the atoms (scatterers). Furthermore, it turns out that for particles with nonzero spin, there exist the phenomena analogous to light polarization plane rotation and birefringence. In this case such phenomena of quasi-optical activity of matter ("optical" anisotropy of matter) are due not only to electromagnetic but also to strong and weak interactions.

The investigations in this field were initiated by V. Baryshevsky and M. Podgoretsky [Baryshevskii and Podgoretskii (1964)], who predicted the existence of the phenomenon of quasi-optical spin rotation of the neutron moving in matter with polarized nuclei, which is caused by strong interactions, and introduced the concept of a nuclear pseudomagnetic field (neutron spin precession in a pseudomagnetic field of matter with polarized nuclei). The concept of a nuclear pseudomagnetic field and the phenomenon of neutron spin precession in matter with polarized nuclei were experimentally verified by Abragam's group in France (1972) [Abragam *et al.* (1972)] and Forte in Italy (1973) [Forte (1973)].

Here we would also mention the paper by F. Curtis Michel [Michel (1964)], who predicted the existence of spin "optical rotation" due to parity nonconserving weak interactions (the phenomenon was experimentally revealed [Forte *et al.* (1980)] and is used for studying parity nonconserving weak interactions between neutrons and nuclei).

Further analysis showed that the effects associated with the optical activity of matter, which we consider in optics, are, in fact, the particular case of coherent phenomena emerging when polarized particles pass through matter with nonpolarized and polarized electrons and nuclei [Baryshevsky (1982a); Baryshevskii (1976a); Baryshevsky (1995b)]. It was found out, in particular, that at high energies of particles (tens, hundreds and thousands of gigaelectronvolts), the effects of "optical anisotropy" are quite significant and they may become the basis of unique methods for the investigation of the structure of elementary particles and their interactions.

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