Preface

This book was written by an experimenter. It summarizes the results of my fifty-year work at A.I. Alikhanov Institute of Theoretical and Experimental Physics on problems of gamma ray interaction with nuclei. I tried to reveal the physical meaning of these results, making the exposition as simple as possible and sometimes resorting to arguments and derivations that could seem insufficiently strict, at least to orthodox theorists. The main part of the book addresses the problem of studying resonant gamma ray absorption and scattering by nuclei. These processes, which are essentially the simplest nuclear reactions, permit, if studied profoundly, revealing very interesting special features that are inherent in phenomena of gamma ray emission and absorption by nuclei, and which are seemingly of a general character. It is noteworthy that the concepts of the nature of the photon that are prevalent among the physics community are inaccurate in many respects, even sometimes erroneous. In particular, the assignment of a well-defined frequency v to a photon of energy $E = hv$ is an approximation because a monochromatic harmonic oscillation is infinite in time, but by no means does a photon, which is produced at specific instant, exist limited during time, ending up in absorption inside a detector or in some substance. This means that the Fourier frequency spectrum of a photon must have a finite width. Also, opinions on the particle-wave duality of the photon differ widely. Recently, an article of the present author where resonant gamma ray scattering on nuclei was considered and where a photon was shown to manifest a spatial and a time extent in this process was rejected by an authoritative Russian physics journal on the basis of reviewer's evaluation. The argument of the reviewer was that the photon is a particle because it experiences photo-absorption even in very finely dispersed powders, and therefore cannot have extensive dimensions. Of course, the statement of the reviewer that, in processes like the photoelectric effect, photons behave as almost quasi point objects, not displaying wave properties, is correct. The same reveals in the behavior of photons in Compton scattering by electrons. However, the other processes exist in which the photon interacts with matter behaving itself like a wave of macroscopic size, not showing any particle property. In the monograph by Robert Wood "Physical Optics" [1], there is a description of an experiment where one observes light diffraction at a grating 3 cm long and measures the resolution of the grating. After covering half the grating with a screen, the resolution becomes lower by a factor of two. Since a stationary diffraction pattern arises owing to the interference of a photon with itself (the interference between of two photons cannot lead to a stationary pattern because of a stochastic character of the phase difference), this means that, under conditions of the experiment being discussed, photons have a size not smaller than 3 cm. Bragg scattering in crystals is yet another process of this type, but, here, it is gamma ray photons rather than optical photons behave as extended waves. In this process, each photon interacts with all crystal atoms within its absorption length, exhibiting no particle properties. A very convincing example is provided by an experiment of a group headed by V.K. Voitovetsky [2], where gamma rays of the ^{181}Ta nuclide were transmitted between the cogs of a rotating gear, the shape of the detected gamma line being measured with the aid of a Mössbauer spectrometer. It was found that, at a large number of gear revolutions per unit time such that the gap between the cogs traverses the gamma beam within 0.1 of the mean lifetime of source nuclei in the excited state, the measured width of the Mössbauer gamma line was much larger than that in the case of a very slow rotation of the gear. This obviously indicated that the gear cogs interrupted the spatially extended wave train of a photon because wave trains shorter than natural ones corresponded to gamma lines of width larger than the natural width. We would like to emphasize that, in no physics process, a photon demonstrates its wave and particle properties simultaneously—either the former or the latter. After being involved in Bragg scattering in a crystal, a photon is recorded by a detector in an event of photo-absorption or Compton scattering; that is, the photon behaves as a particle that lost completely the wave properties that it has just revealed. However, this does not mean that the wave transformed into a particle immediately after Bragg scattering. If, instead of a detector, one places a second crystal on the path of a photon that experienced Bragg scattering, and if the Bragg conditions hold in this crystal, then the photon would be able to undergo Bragg scattering once again with a sizable probability—that is, to exhibit anew its wave properties. At the same time, a photon that has shown particle properties in an event of Compton scattering in a detector can thereupon interact in a wave manner with a crystal (under Bragg conditions other than those in the first case, because the photon energy changed after scattering), transforming from a particle into a wave again. The question of how and why such transformations occur is one of the most mysterious in modern physics.

The ensuing exposition is organized as follows. In the first chapter, we consider theoretically the process of resonant gamma ray scattering by nuclei. We are interested in a question of how the angular distribution of resonantly scattered gamma rays depends on the perturbing action of magnetic fields. Solving this particular and seemingly trivial problem, we arrive at conclusions that give sufficient grounds to take a fresh look at some special features of processes involving gamma ray emission and absorption by nuclei. In the second chapter, we describe experiments performed by our group and devoted to measuring unperturbed and magnetic-field-perturbed angular distributions (ADs) of resonantly scattered gamma rays of ^{182}W and ^{191}Ir. Those experiments confirmed the prediction of the theory that the result of perturbing ADs depends on the width of the spectrum of gamma rays incident to a resonant gamma ray scatterer. At the end of this chapter, we show that important conclusions follows from the theoretical and experimental data described in it: the mean lifetime of nuclei in an excited state depends on the mode of its excitation, and processes of gamma ray emission and absorption by nuclei have a protracted character. In the third chapter, we consider in detail the problem of gamma resonant excitation of long-lived isomeric states of nuclei. Experimental investigations of this problem revealed a glaring contradiction between present-day theoretical predictions, which require, among other things, that the Mósbauer gamma line emitted in the decay of ^{109}Ag nuclei that were in the isomeric excited state characterized by an energy of 88.03 keV and a mean lifetime of 57 s must be broadened by five to six orders of magnitude in relation to the natural width, and the experimental results of three research groups (including ours), which obtained data indicating that the relative broadening of this gamma line does not exceed one to two orders of magnitude. So small a broadening of the Mósbauer gamma line of the ^{109m}Ag isomer permitted implementing the idea of a gravitational gamma spectrometer and directly measuring the profile of the Mósbauer gamma resonance in this isomer. The use of a traditional Mósbauer spectrometer for this purpose is technically impossible because this would require creating a device capable of moving a gamma source with respect to the absorber at a velocity of about 10^{-12} cm/s; that is, it would be necessary to push it forward over a distance per second nearly equal to the diameter of the silver-atomic nucleus, and to measure simultaneously this velocity by some method. The principle of operation of the gravitational gamma spectrometer based on the ^{109m}Ag isomer is described in the fourth chapter. Its resolution is about eight orders of magnitude higher than the resolution of usual Mósbauer spectrometers employing gamma rays of the ^{57}Fe nuclide. In the next chapter, we describe our experiments devoted to exploring the resonant scattering of annihilation photons by nuclei, whereupon (in the last chapter) we show how one can use this phenomenon to study the shape of Fermi surfaces in metals.

Some other experiments performed by our group with gamma rays are discussed at the end of this book along with the ideas of experiments that have yet to be conducted.

Some of the experiments described here were performed by methods that seem obsolete from the modern point of view, but I deemed it necessary to tell about them because they were an inalienable link in the chain of experiments that led to important conclusions both in what is concerned with the dependence of the mean lifetime of nuclei in an excited state on the method of excitation and in what is concerned with the duration of nuclear radiative processes.

One comment on the notation used is in order. Vector quantities appearing in some equations are printed in boldface.

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A.V. Davydov

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