CHAPTER I

DUALISM VERSUS QUANTUM MECHANICS

'We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.'

NEWTON

1. *Description, interpretation, explanation*

The principal aim of this book, apart from criticizing the current quantum philosophy of the Schools, is to give an *explanation* of the laws of the quantum theory on a simple and elementary non-quantal basis. This program may look like a futile excursion into thin air to a generation of physicists who have been told again and again that the quantum theory can *not* be reduced to anything more fundamental, that its laws are basic and inexorable features of Nature—an opinion which seemed to be confirmed by the many abortive efforts, during the first decade of this century, to detect a flaw in classical statistical mechanics so as to make room for Planck's discrete energy levels, efforts which proved entirely futile. Indeed, if one wishes to derive the quantum laws from a more elementary basis, one must start from probabilistic considerations right away, forget about classical mechanics, and be glad if the latter comes out as a statistical approximation.

But then, what does it mean *explaining* the quantum laws, and physical laws in general? For example take the magnetic properties of atoms. They became a topic of intense interest through Zeeman's magnetic splitting of spectral lines, afflicted with certain unexpected features, however. The Anomalous Zeeman Effect was deciphered in 1922 by the author through reduction of the observed atomic frequencies to magnetic energy levels, revealing various gyro-magnetic or

g-factors of unknown origin, involving half-quantum numbers for angular momenta in a vector model. The quantum number $\frac{1}{2}$ was later *interpreted* by Goudsmit and Uhlenbeck as peculiar to a spinning electron. Finally, the spin was *explained* by Dirac through a combination of relativity theory and quantum principles. The aim of this book is to go still farther and to explain the quantum principles themselves, that is to show them to be consequences of still more elementary principles known from pre-quantal physics.

For another example of description *versus* explanation take the theory of relativity. A student of physics learning that travelling rods contract, traveling clocks slow down, and mass defects correspond to surplus energies according to $E = mc^2$ would hardly be satisfied with being told that these are basic and inherent qualities of matter which can no longer be explained. But Einstein's derivation of the relativistic phenomena from general postulates of symmetry and invariance applied to a combination of mechanics and optics gave the desired explanation. Why then should we accept the quantum laws such as $E = h\nu$ as irreducible and inherent qualities of the physical world, or even less convincing as 'consequences of the dualism of the wave picture and the particle picture'? (For these quotations, refer to Chapter VIII.) The belief in a dual nature of matter and of light as *fundamental* has indeed blocked the search for a better understanding of the quantum theory for more than three decades, promoting the view that the student 'after learning the [mathematical] tricks of the trade' will finally 'understand that there is nothing to be understood' about the 'why' of the quantum laws. The present book is to challenge this purely descriptive approach; it intends to show that the perplexing wavelike interference of probabilities and the quantum rules, $E = h\nu$, etc., can be *explained* as necessary consequences of general postulates of symmetry and invariance imposed on the structure of a probability metric—as Einstein's $E = mc^2$ has been derived from similar postulates applied to a combination of mechanics and optics in which the velocity of light is the measure of space and time.

The aim of the first chapter is to show that electron diffraction and related wave like phenomena can be explained by pure mechanical particle action without wave interference.

2. *Diffraction through crystals*

The chief exhibit in defense of a dual nature of matter was, and to many physicists still is, the famous matter diffraction experiment. A homogeneous ray of electric charge, clearly consisting of individually countable electrons with concentrated charges, is sent toward a crystal from which the ray is reflected. As required by the conservation laws of energy and momentum, the angle of reflection equals that of incidence. The curious fact is, however, that reflection takes place only at certain discrete angles of incidence so as to produce discrete points or lines rather than a broad band of reflected intensity on a film, a most amazing sight and one of the showpieces of atomic physics. What could be the cause of this selective reflection?

It turned out that one can *calculate* the discrete angles of reflection by imagining that each single electron, arriving with momentum p, spreads out near the crystal into a broad wave aggregate of wave length $\lambda = h/p$ (h is Planck's constant) covering the whole crystal, that these 'matter waves' are reflected simultaneously from the parallel lattice planes spaced at distance l, whereupon wave interference, according to the Huyghens' principle of superposition, yields strongly reflected intensities only in those angular directions which belong to path differences of one, or two, or n wave lengths. Having done their duty, the waves re-form into particles again, as evident from the statistical build-up of the reflected pattern by individual impacts on a film. Interference maxima occur in those directions θ which satisfy the rule (Fig. 1a):

$$2l \sin \theta = n\lambda \quad \text{(Bragg)} \tag{1}$$

in which the left-hand side represents the path difference of two wave trains reflected from two subsequent lattice planes.

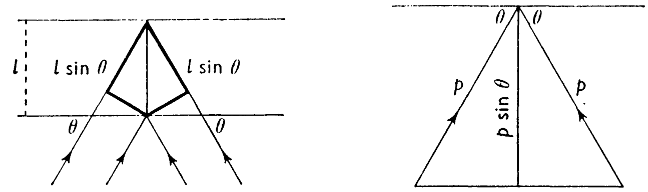

Fig. 1 a, b

There is no objection to the supernatural or, as others see it, broadminded(?) transmutation hypothesis, provided that it is regarded as a first probing step into unknown territory, pending further clarification. But instead of trying to clarify the mystery on physical grounds, physicists are committed to regard double manifestation as an unshakable truth, and evade the problem of the *real* constitution of matter, either waves or particles, by a sophisticated skepticism toward the idea of physical reality. Maybe everything from trees to neutrinos and galaxies is a mental construction fashioned into a Gestalt out of chaotic sense impressions; we know this anyway. But in science, as in ordinary life, the term 'real' is meant in no other sense than that a cloud really consists of individual water droplets, although it may appear as a continuous gray substance. And an apparently smooth image on a film in reality consists, as closer inspection shows, of many individual grains blackened one after another in a statistical manner. Nor does it help to remove the dilemma of diffraction if one replaces the supernatural forth-and-back transmutation by a mysterious 'dual manifestation' (a purely linguistic device), or if one speaks of the wave 'picture' in reaction to the crystal, and of the particle 'picture' away from the crystal. The task of physical theory is not inventing figures of speech but understanding atomic phenomena by a consistent theory representing one physical reality. If electrons are once condensed within a range of 10^{-12} centimeter or less, how can they ever spread out—or, as some would say, manifest themselves as though spreading out—over a billion times that range? Although it is generally believed that, without double manifestation, the diffraction of matter and other coherence phenomena would be impossible to explain, the impossible was achieved as early as 1923 by the American physicist W. Duane, one of the almost forgotten pioneers of modern quantum mechanics.

3. *Mechanics of diffraction without waves*

According to Duane (1), the incident matter particles do not spread out as continuous matter waves, or manifest themselves as though they did. It is the crystal with its parallel lattice planes which is already spread out in space and reacts as one rigid mechanical body to the incident particles under the conservation laws of mechanics with the following restriction (Duane's quantum rule for linear momentum):

A body periodic in space with linear periodicity of length L is thereby entitled to change its linear momentum p parallel to L in amounts $\Delta p = h/L$.

The foremost example of a space-periodic body is a crystal. If l is the mutual distance within a set of parallel lattice planes, the crystal contains not only the periodicity $L = l$ but also higher periodicities $L = \frac{1}{2}l$, $\frac{1}{3}l$, and so forth; hence, according to Duane's quantum rule, it can change its momentum perpendicular to the lattice planes in amounts

$$\Delta p = h/l,\ 2h/l,\ 3h/l,\ \ldots\ nh/l. \tag{2}$$

When these selective momenta are transferred from the crystal to the incident particles, the latter are deflected into exactly the same discrete directions which can also be *calculated* according to the Laue-Bragg wave interference theory. Yet this result is now obtained in a purely mechanical particle fashion, without double manifestation or any other 'causal anomaly' (Reichenbach's term) being involved. Indeed, when a particle of momentum p is incident and reflected at the same angle θ, as required by the conservation laws, its momentum component parallel to L changes as much as $2p \cdot \sin\theta$. The quantum rule above then yields the relation (Fig. 1b, p. 4).

$$2p \cdot \sin\theta = nh/l \text{ (Duane)} \tag{3}$$

which is identical with Bragg's wave rule (1) by virtue of translating the momentum p into a wave length, $\lambda = h/p$, near the crystal and retranslating into the particle momentum p again after the reflection—only that *Duane's rule yields the same observed deflection directly without appealing to a wave interlude*. Therefore, the idea of a dualistic change from matter particles to waves is a quite unnecessary, if not fantastic, invention though it may sometimes be helpful to use: '*Se non è vero, è ben trovato*'.

Duane's quantum rule for the change of linear momentum by a body of periodicity L is by no means invented *ad hoc* (in contrast to the duality doctrine). It rather is the legitimate counterpart to the two familiar quantum rules for the energy E and for the angular momentum p_ϕ, namely Planck's rule, $\Delta E = h/T$, and Sommerfeld-Wilson's rule, $\Delta p_\phi = h/2\pi$, for bodies periodic in time with period T (harmonic oscillator) and periodic with respect to rotation through 360 degs. $= 2\pi$ (every body). If the system contains several inherent time periods T_1, T_2, . . . (an atom, as revealed by its spectrum) then it can change its energy in any one amount $\Delta E = h/T_n$ (Bohr's frequency condition). If the body has higher angular periodicities, if it is a regular polygon of periodicity $2\pi/n$, then it can change its angular momentum in amounts $\Delta p_\phi = nh/2\pi$. All three quantum rules are of course very perplexing. The common opinion is that we must accept them at face value, as fundamental and irreducible quantum principles. Yet, as we intend to show later in this study, they can be *explained* as being necessary consequences of simple and general postulates of symmetry and invariance, without any quantum ingredients to start with. In the present Introduction we take the quantum rules for granted.

Strangely enough, however, whereas the first two quantum rules are recognized as the most important instruments of the quantum theorist, the third rule for the linear momentum, $\Delta p = h/L$, is hardly ever mentioned. Yet, by way of Duane's theory of selective reflection of particles from a crystal, it deals a fatal blow to the doctrine of a wave-particle duality of matter, to the dogma that we must be content with the 'extravaganza' (Schrödinger's term) of two alternating pictures instead of one physical reality. Thus, when we are told authoritatively:(2) 'Quantum mechanics has discovered that the same physical object, for example an electron, appears in two seemingly exclusive forms', then we must reply that, in the contrary, quantum mechanics has discovered that even such wavelike phenomena as matter diffraction through crystals can be understood in a consistent unitary way as produced by matter particles alone obeying the conservation laws of mechanics under special restrictions, known as quantum rules, which apply to bodies containing periodicities in time and space. Electrons always behave as particles; *they never misbehave as waves*. It is one thing to instruct the adept that he may obtain results for the statistical behaviour of many particles by using a wavelike mathematical method, for example the Schrödinger equation, and then re-interpret the wave intensity as a statistical distribution density of particles. It is quite another thing to proclaim *urbi et orbi* that matter has a dual physical nature, that it appears as two pictures, sometimes as waves, another time as particles. Although this doctrine has attracted much attention, it has become a fallacy by virtue of Duane's third quantum rule which certainly ought to be granted equal time with the two other quantum rules.

One has retorted here: 'Duane regards the crystal as a mechanism acting through its periodic space components, whereas others assume that electrons occasionally spread out. What difference does it make?' There is a large difference in scientific outlook indeed. According to duality, a small particle miraculously becomes periodic and spreads out in space.

According to quantum mechanics and Duane, the crystal is there already; it is periodic and extended in space without extra 'manifestations'. Duality asks us to believe that a *thing* transforms itself into another thing, or acts as though it did. This is magic and will be denoted as such throughout this book. Quantum mechanics requires us only to accept an apparently strange (quantum) *action*. And this action can be explained as being quite natural (Chapters VI and VII) on elementary grounds. Duality is an extremely implausible ideology admittedly introduced *ad hoc* in order to cope with an apparent paradox, whereas Duane's quantum rule is legitimate physics. And yet, the dogma of a supernatural double manifestation has become so solidly entrenched today that one recalls Sidney Hook's general remark: 'The difference between science and religion is that the former wishes to get rid of mysteries whereas the latter worships them.'

It must be emphasized here that there is a large difference between the rules of quantum mechanics, $\Delta E = h/T$, $\Delta p = h/L$, and $\Delta p_\phi = h/2\pi$, for the energy and momentum exchange of physical bodies periodic in time and space, as against the formulas $E = h\nu$ and $p = h/\lambda$, which translate mechanical data of single particles into the picture of waves. Either the rules for energy and momentum, or the translation of particles into matter waves represent legitimate physics. I still trust that quantum theorists, when seriously challenged to choose between the two sets of rules, will decide in favour of the physical rules for energy and momentum exchange, and will recognize the translation rules as ideological crutches. This is not to dispute the tremendous influence exercised by de Broglie's original idea of matter waves and its value for heuristic purposes. But if Newton is right in the motto of this chapter, then the unitary theory of matter particles, that is quantum mechanics, is preferable to the uneconomical and *entirely superfluous* hypothesis of dualism, and is preferable also to a unitary theory of waves which is possible only at the cost of very great complications (Section 36).

Dualism stops at the observation that matter sometimes *looks like* particles and at other times *looks like* waves; so let us not be one-sided and take this 'looking like' as a principle. However, there are people who are less broadminded and would like to know what is behind the two subjective pictures or models. To them the answer is contained in the third quantum rule of mechanics which is as legitimate as the other two.

The reason that Duane's third quantum rule was not immediately recognized as a way out of the duality paradox was historical: Duane proposed his statistical particle theory of diffraction for X-rays in support of the photon theory of light. At his time (1923) diffraction of electrons was not yet discovered. Moreover, the quantum rule $\Delta p = h/L$ for bodies of periodicity L in space seemed artificial and conceived *ad hoc*. Since 1926, however, all three quantum rules have been victorious. There is no reason for ignoring the third rule alone, and relying instead on a principle of duality which gives a more or less fitting name to a dilemma rather than solving it in a scientific manner. Today, after endless repetition, a dual nature of matter may seem as obvious and indisputable to the experts as the immobility of the Earth seemed to Galileo's learned colleagues who refused to look through his telescope because it might make them dizzy. Yet Duane did as much to dissolve the phantom of duality as Gregor Mendel did to dispose of the age-old myth of inheritance through continuous blood mixture in favor of the statistical gene-particle theory. But Duane will probably have to wait as long as the Austrian abbot before his statistical interpretation and explanation of the wavelike diffraction phenomena are recognized as decisive steps toward modern quantum mechanics, as the Missing Link between wavelike appearances and particle reality.

4. *The two-slit experiment*

Let us next consider the much-discussed experiment of matter diffraction through a screen with one or two slits. A single slit yields a diffuse intensity distribution centered around the direct line of incidence of the matter ray. If now another adjacent slit is opened, various formerly bright places become dark. How can one explain that the *opening* of a second slit *blocks* particles from places at which they formerly arrived, without temporary transformation of the particles into waves and their interference? This is indeed the crucial question, discussed in scores of books, magazines, symposiums, and keynote speeches. The scientific solution of the problem is contained in a well-neglected investigation by Ehrenfest and Epstein(3) representing a further development of Duane's theory. An incident particle does not react to this or that individual slit (or bar in a reciprocal experiment), nor does it react to this or that lattice point of a crystal. A slit is more than a mere Nothing; it is a Nothing with something around. And the latter is as important as the former. A screen with one slit has periodic space components of various lengths L composing its geometrical shape; a screen with two slits has a different set of L's. And since the several components L give rise to impulse transfers $\Delta p = h/L$ respectively, the two cases of one and two slits yield different deflected angles with different intensities. The diffraction patterns produced statistically by deflected particles agree in both cases with those obtainable *also* via translation into waves and retranslation into particles. Yet the hypothesis of two alternating models to account for the observations proves expendable again.

Therefore, to the eternal question 'through which of the two slits does the electron pass' (supposing it does not perform the miracle of spreading out over both slits), the answer is: 'For its contribution to the diffraction pattern it does not make any difference where exactly the deflection takes place.' The electron changes its momentum in reaction to the harmonic components of the matter distribution of the screen with two slits as a whole; and the deflected electron may not even be identical with the incident one. All that matters is conservation of charge and of total momentum during the reaction between electron and diffractor.