Personal Reminiscences

R. Glocker

Early in 1912 I began research in the Physics Institute of the University of Munich under Geheimrat Dr. W. C. Röntgen. This gave me the opportunity of following the fundamental experiments of M. von Laue, W. Friedrich and P. Knipping from close by in the most literal sense. For the scene of these experiments was the adjoining Institute for Theoretical Physics whose Head was Professor Dr. A. Sommerfeld. The latter had, shortly before, and in a far-seeing way, appointed the experimentalist W. Friedrich, a pupil of Röntgen, to the newly created position of second assistant. M. von Laue was connected with the chair of theoretical physics as Privatdozent.

When the disturbing hissing of arc lamps in projectors in some of the main lecture rooms of the University was traced to an interrupter in Sommerfeld's Institute, this was the first indication that something mysterious was in the making there. It soon became known that the experiments had at long last revealed the wave nature of X-rays by causing them to be diffracted in a crystal. In July 1912 M. von Laue gave the details in a talk to the Physics Colloquium in Sommerfeld's small lecture theatre. Some forty physicists and crystallographers attended, among them Professor Ernst Wagner, Röntgen's senior assistant. He was stimulated by the talk to propose the following crucial experiment for testing the correctness of Laue's theory: if one of the many secondary rays obtained by diffraction from a first crystal is picked out by a diaphragm behind the crystal and allowed to fall on a second crystal parallel to the first, then only very few secondary rays should be produced behind the second crystal, and their wave-lengths should stand in simple ratios, like those of the harmonics to the fundamental wave-length in acoustics. The performance of this experiment was assigned to me as my thesis subject by Röntgen.

Because the secondary rays are so much less intense than the primary

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rays, exposure times of many hours were to be foreseen. Only he who has himself worked with gas-containing X-ray tubes can appreciate what was implied in such exposure times. Every five or ten minutes a little palladium tube, whose open end was sealed through the glass wall of the X-ray tube, had to be heated to dull red glow by holding a small spirits flame under it, so that minute quantities of hydrogen entered the tube by diffusion through the palladium walls. Besides, the current breakers, and the induction coils were not built for lasting loads and soon broke down. This was considerably improved when, at about that time, rotating high-voltage rectifiers became available. In view of the long exposure times all attempts were made to increase the sensitivity of the detection of X-rays. Photographic plates were prepared with two sensitive layers, one on top of the other. In order to achieve a uniform development the top layer was detached after the normal time of development, and the development of the bottom layer continued. For viewing, the dried layers were again superimposed.—A considerable gain in intensity was achieved by letting the beam impinge on the cube face of the rocksalt crystal under a glancing angle of only a few degrees.

At the end the desired effect was obtained, in spite of the initially gloomy prospects. The photographic plate behind the second crystal showed a diffraction pattern of which all spots could be explained by the monochromatic wave-lengths λ, $\lambda/2$, and $\lambda/3$.

E. Wagner was a physicist who liked to work with the utmost precision. I always remember one of his sayings: 'I like to work so precisely as if I were to live forever.' Since Röntgen too was very critical when examining whether a paper was mature for publication, I have often been wondering, during my four decades of scientific production, what parts of an investigation are of real importance for the intended aim, and which are not? To deal with everything in uniform detail would lead to a low efficiency of publication. The younger generation is prone to follow the opposite extreme.

The two-fold importance of Laue's discovery for Physics was quickly recognized. While the determination of the wave-lengths of the characteristic X-ray emission gave a great lift to atomic theory, the exploration of the internal structure of crystalline, and later of amorphous bodies soon assumed an extent of applications in science and engineering which surpassed all early expectations. A third, more recent branch of engineering applications of the same principles of diffraction is, however, less well known. This is the determination of elastic stresses in engineering work pieces. Under stress, the distances of the atomic netplanes of a crystalline material change, and this minute change can be measured by back-reflection X-ray methods. By means of the known elastic constants the stresses in the material can be found from these changes. In other words, X-rays detect changes of distance, with the atoms serving as scale marks. This method differs from the usual mechanical ones of finding tension in that only the elastic strain is being measured, and not the sum of elastic and plastic deformations. It further gives the absolute value of the stress and is, for this reason, particularly well suited for the determination of residual and other internal stresses. Also the method leaves the work piece intact. A drawback of the method is that the small penetrating power of the necessarily very soft X-radiation producing back reflections limits the stress determination to a thin surface layer.

If a metal is subjected to alternating loads, the incipient 'fatigue', which precedes fracture, can be recognized from the fact that the stress indicated by the X-ray method diminishes while the alternating load remains unchanged. This shows that the strains produced by the load are no longer elastic, but partly plastic. The region in which fatigue occurs is extremely limited; in a steel rod with a pressure-tension load along the axis fatigue develops on the surface in an area of a few square millimeters or less.

Since the discovery of X-rays was of such eminent importance for medicine, one might well ask what further importance X-ray *diffraction* added. The influence is less obvious but undeniable. One of the pillars of X-ray therapeutics is dosimetry, the measurement of the radiation energy penetrating to a given point in the human body and becoming biologically efficient there. The interaction between X-rays and matter could be clarified only after one had succeeded to measure X-ray wave-lengths and to pick out or produce definite wave-lengths. All physical, chemical, and biological action of X-rays is an indirect one, carried out by way of photoelectrons, Compton electrons, or, for extremely hard radiation, electron pairs. Given matter of known chemical composition, the dosis can be calculated for any X-ray wave-length by applying known physical laws. Alternatively, it is possible to prepare test materials, and in particular fluorescent ones, which have the same composition as muscle or bone. If the intensity of the fluorescent light is measured by means of a photomultiplier, the dosis can be obtained which will be received at the same spot in muscle or bone tissue. The long discussed problem of the existence of selectively efficient kinds of X-rays, similar to the selective action of ultraviolet light on skin erythema, has been answered by showing that the absorption spectrum of X-rays in biological material is a continuous and not a line spectrum.

References

E. Wagner, 1913. *Physikal. Zeitschrift 14,* 1232; R. Glocker, 1914. *Physikal. Zs. 15,* 401 and *Annalen d. Physik* (Lpz.) 1915, *47,* 377.

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