X-Ray Sources

2.1 Introduction

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X-rays, first detected by Wilhelm Conrad Röntgen in 1895 [1], are electromagnetic waves with a spectrum spanning from about 80 nm wavelength (about 15 eV) adjacent to the vacuum ultraviolet down to about 0.001 nm (about 1.2 MeV) overlapping to some extent the region of γ-rays (Fig. 2.1). Electromagnetic radiation above 1 MeV generated by nuclear processes is usually called γ-radiation while the radiation below 80 nm wavelength, generated by electrons slowed down in the outer field of an atomic nucleus or by changes of bound states of electrons in the electronic shell of an atom, is called x-radiation. The division into different regions of X-rays and γ-rays is to some extent artificial and sometimes misleading.

The x-radiation generated by the slowing down processes of electrons is called “Bremsstrahlung” and has a continuous spectrum with a sharp termination \( \lambda_t \) at the short wavelength side corresponding with the maximum kinetic energy \( E_{\text{kin}} = e \cdot U \) of the electron

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\lambda_t[\text{nm}] = \frac{c}{\nu_t} = \frac{ch}{E_{\text{kin}}} = \frac{1.24}{U[\text{kV}]}.
\]

Electron transitions between inner electron shells of the atom may generate the so-called characteristic x-radiation, that is a line emission which can be attributed unambiguously to the elements. According to the electronic shell structure of the elements such characteristic radiation is to be expected beginning with sodium (e.g., Na-L\( \alpha \) with an excitation energy of 55 eV).

In X-radiation sources, for practical purposes, mainly two different principles are used: first, the spontaneous radioactive decay of certain isotopes, and second, the interaction of artificially accelerated electrons with matter in X-ray tubes or with magnetic fields in accelerators or storage rings.
Historically, the first X-ray generator used by W.C. Röntgen [1] was an ion tube (Hittorf–Crooks-tube, air filled at reduced pressure). Electrons were produced by ion bombardment of a cold cathode in a high voltage gas discharge. The electrons are accelerated by the tube voltage onto the anode generating X-rays. These ion tubes are almost out of use since they have a short lifetime, are instable and difficult to control. W.D. Coolidge [2] introduced the hot filament electron emitter in a high vacuum X-ray tube. This schema turned out to be very effective and is also widely used at present. A very extensive and specific development of X-ray tubes of all kinds for every particular purpose started in the past and is still progressing. New technologies and new materials are forming the basis for new highly specialized X-ray tubes.

Field electron emitters instead of thermo-electron emitters were tried repeatedly in DC X-ray tubes, because it appeared to be attractive to get rid of the clumsy hot cathode with its heating circuit, which in many cases has to run at high potential. Recently, promising results with carbon nano tubes as field electron emitters have been obtained and their technical application seems within reach [3].

A wide variety of X-ray tubes is now available, from low power of a few Watt up to very high power to tens of kW for DC-, intermittent or short pulse operation specialized for application in all fields. An overview on X-ray tubes with emphasis on the requirement of X-ray analysis is given in Part 2.2.

A particular motivation for new developments of X-ray sources was provided by the recent progress in X-ray optics such as glass capillary optics, Fresnel and Fresnel–Bragg optics as well as HOPG crystals. The efficiency of these optics depends critically on the brilliance of the X-ray source and the compact design of the source. The anode spot should be well focussed and the optics should be mounted as close as possible to the anode spot with the aim to catch as much of the diverging radiation as possible. This allows to reduce the tube power well below 50 W and to achieve short measuring times at improved local and energy resolution. In consequence, different manufacturers are now offering first samples of miniaturized low power microfocus X-ray