

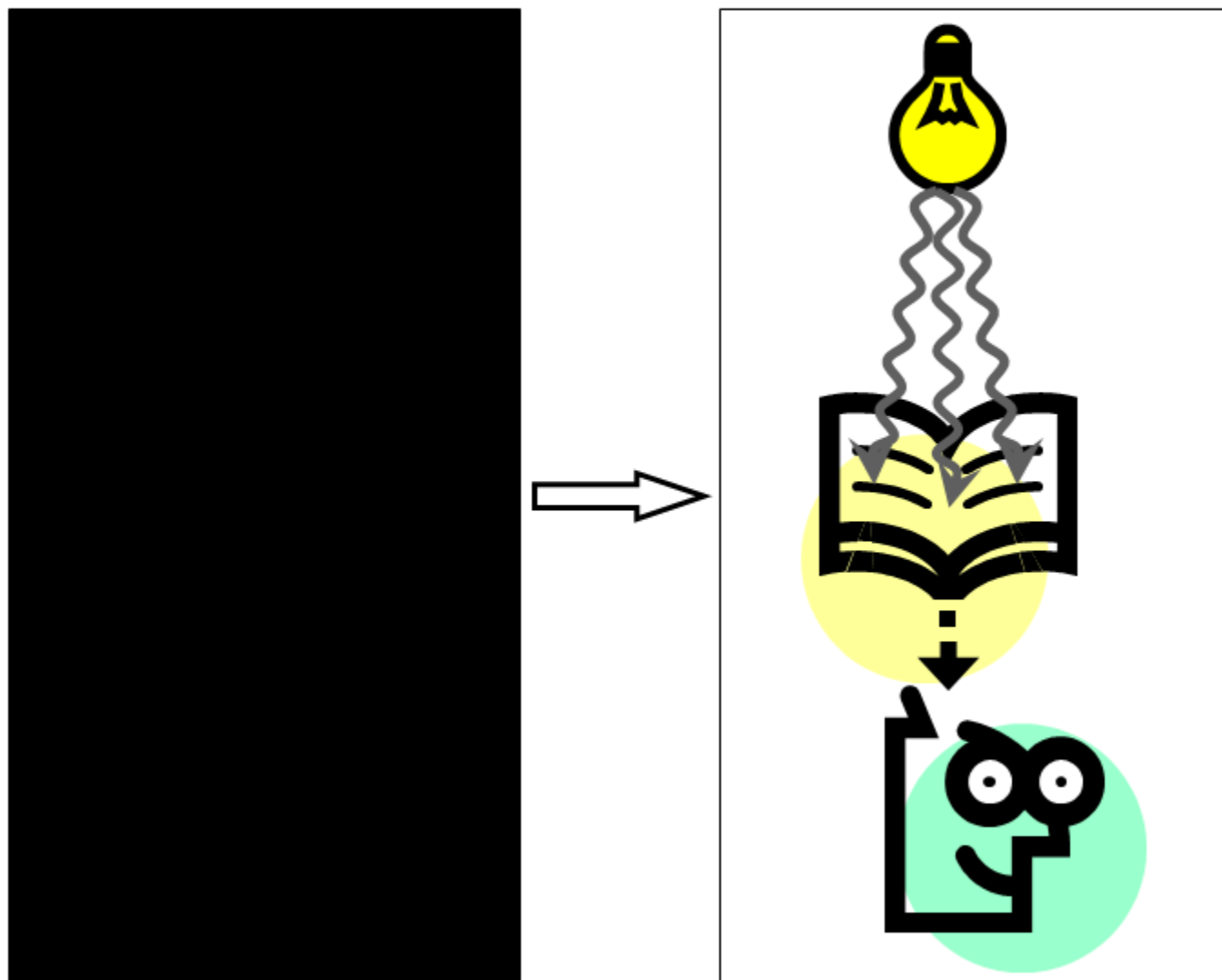
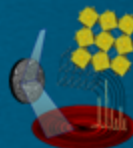
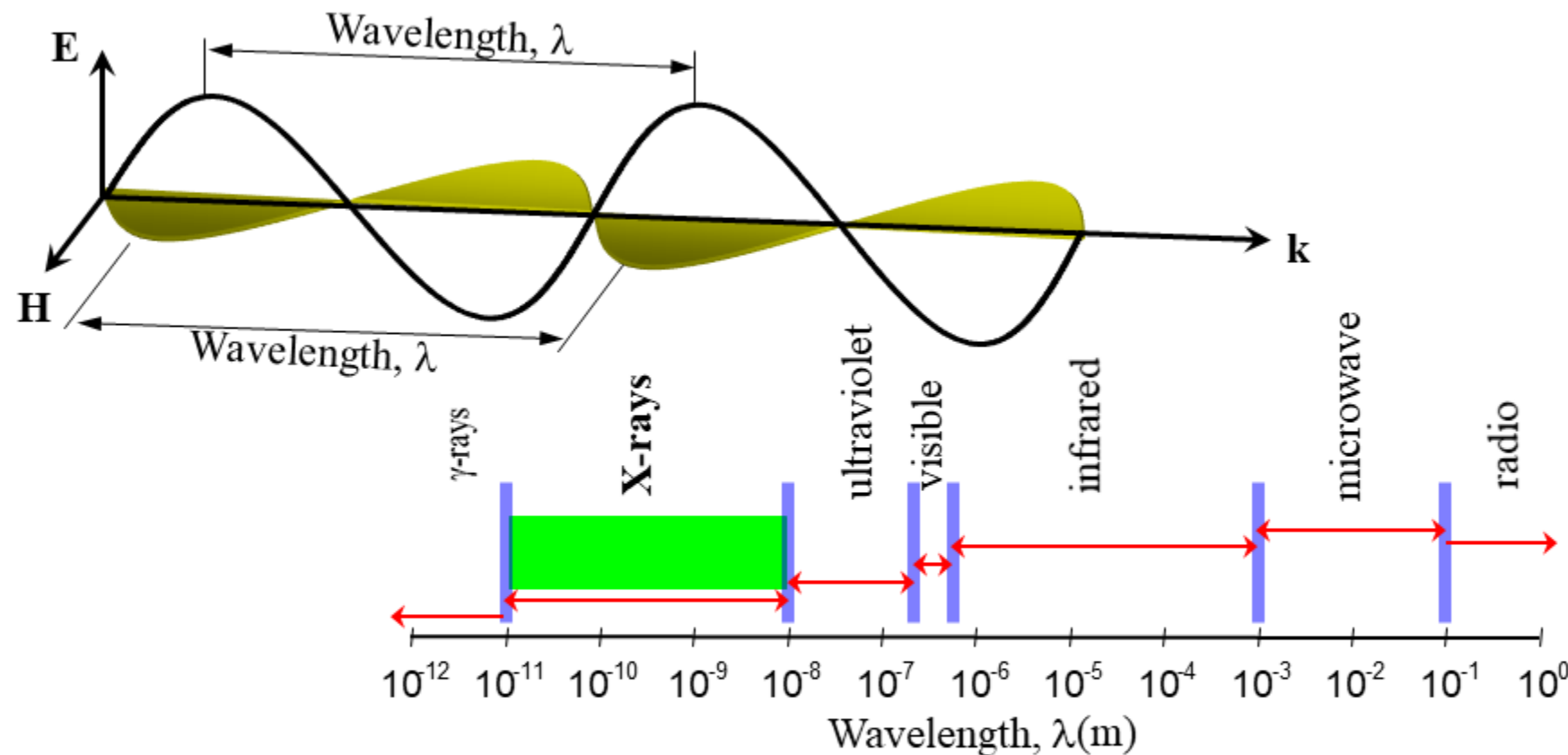
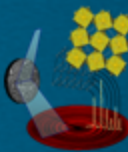


Figure 6.1. The illustration of an observer placed in the absolutely dark room with a book (*left*) and the same room with the light source producing visible rays of light (*right*).



De Broglie equation:

$$\lambda = \frac{h}{mv} \quad \text{Eq. 6.1}$$

where:

h is Planck's constant
($h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$),
 m is the particle's rest mass,
 v is the particle's velocity'

Figure 6.2. *Top* – the schematic of the transverse electromagnetic wave in which electric (**E**) and magnetic (**H**) vectors are mutually perpendicular, and both are perpendicular to the direction of the propagation vector of the wave, **k**, where $|\mathbf{k}| = 1/\lambda$. The wavelength, λ , is the distance between the two neighboring wave crests. *Bottom* – the spectrum of the electromagnetic waves. The range of typical X-ray wavelengths is shaded. The boundaries between different types of electromagnetic waves are diffuse.

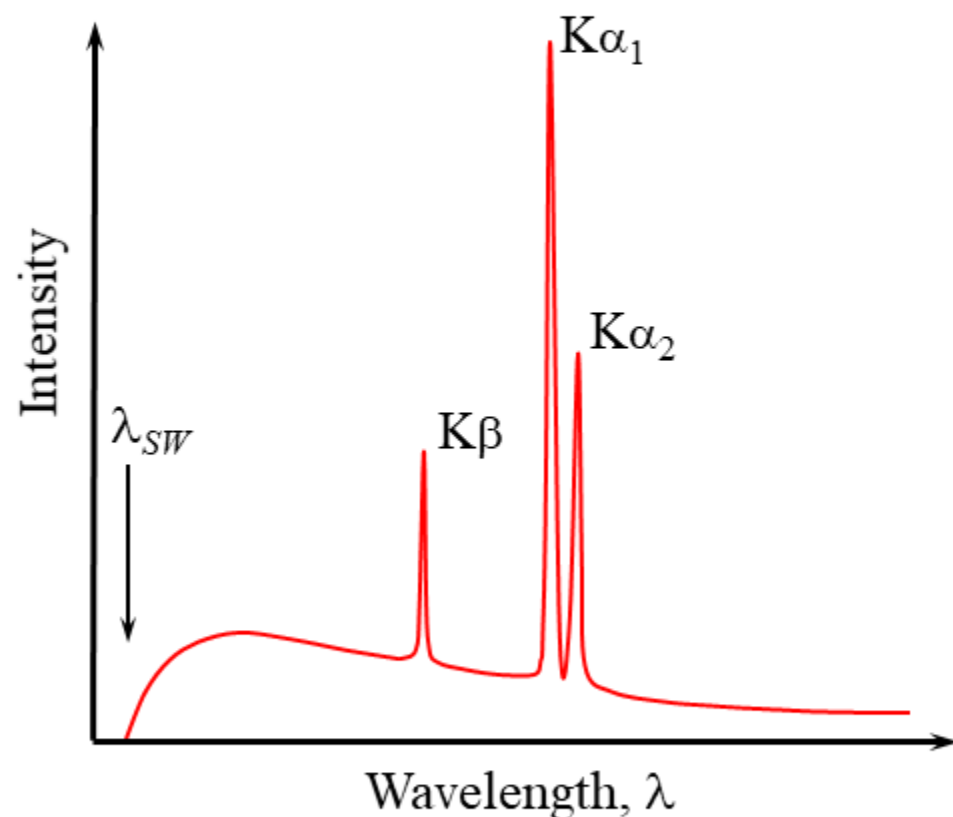
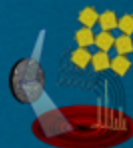


Figure 6.3. The schematic of a typical X-ray emission spectrum, for clarity indicating only the presence of continuous background and three characteristic wavelengths: $K\alpha_1$, $K\alpha_2$, and $K\beta$, which have high intensities. The relative intensities of the three characteristic spectral lines are approximately to scale, however, the intensity of the continuous spectrum and the separation of the $K\alpha_1/K\alpha_2$ doublet are exaggerated. Fine structure of the $K\beta$ spectral line is not shown for clarity. The vertical arrow indicates the shortest possible wavelength of white radiation, λ_{SW} , as determined by Eq. 6.4.

The equation relating the shortest possible wavelength (λ_{SW} in Å) and the accelerating voltage (in V).

$$\lambda_{SW} = \frac{1.240 \times 10^4}{V} \quad \text{Eq. 6.4}$$

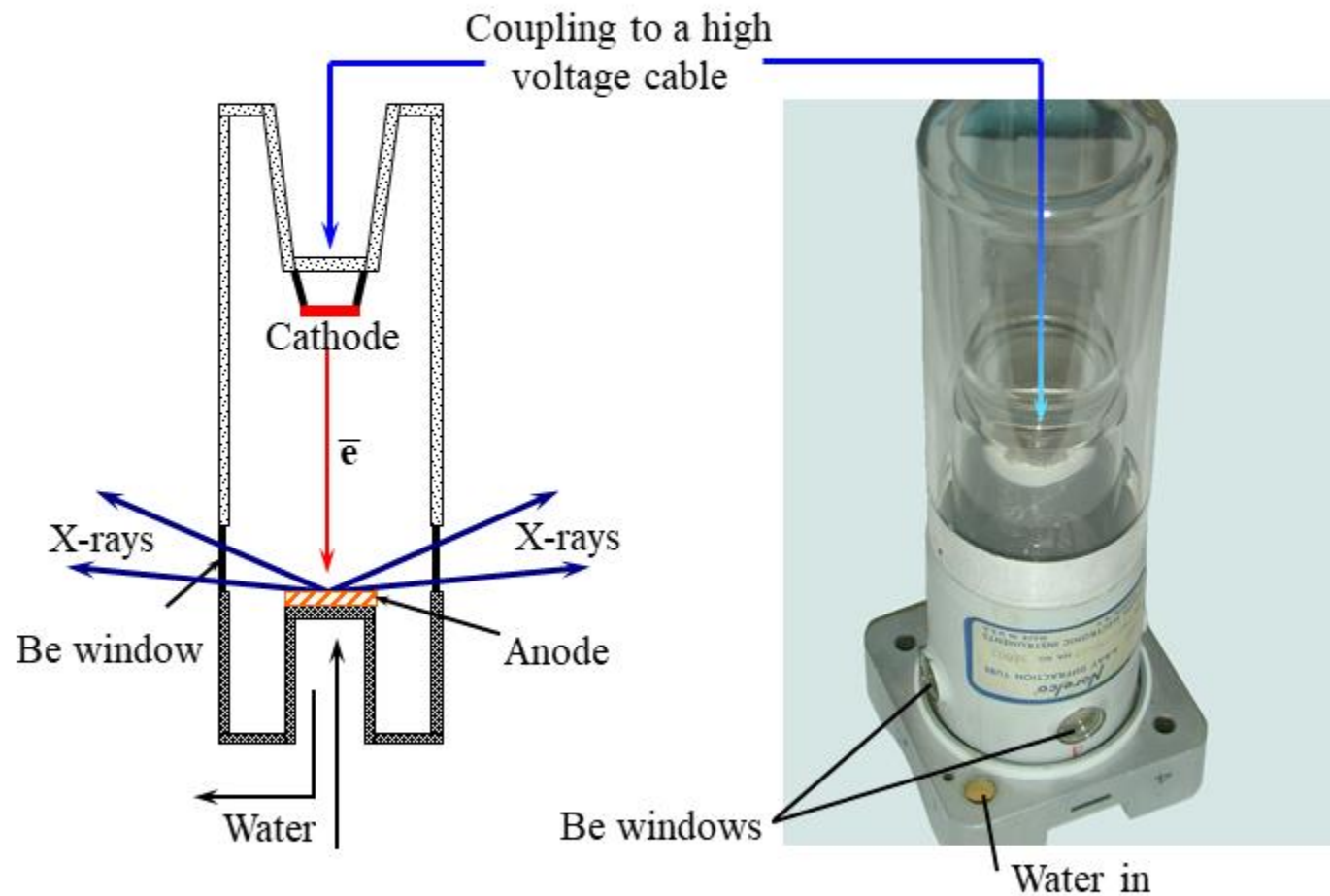


Figure 6.4. The schematic (*left*) and the photograph (*right*) of the metal/glass sealed X-ray tube. The bottom part of the tube is metallic and it contains the anode (high purity copper, which may be coated with a layer of a different metal, for example, Cr, Fe, Mo, etc., to produce a target other than copper), the windows (beryllium foil), and the cooling system. The top part of the tube contains the cathode (tungsten filament) and it is made from glass or ceramics, welded shut to the metal canister in order to maintain high vacuum inside the tube. The view of two additional windows (a total of four) and the “water out” outlet is obscured by the body of the tube (*right*). High voltage is supplied by a cable through a coupling located in the glass (or ceramic) part of the tube. Both the metallic can and the anode are grounded.

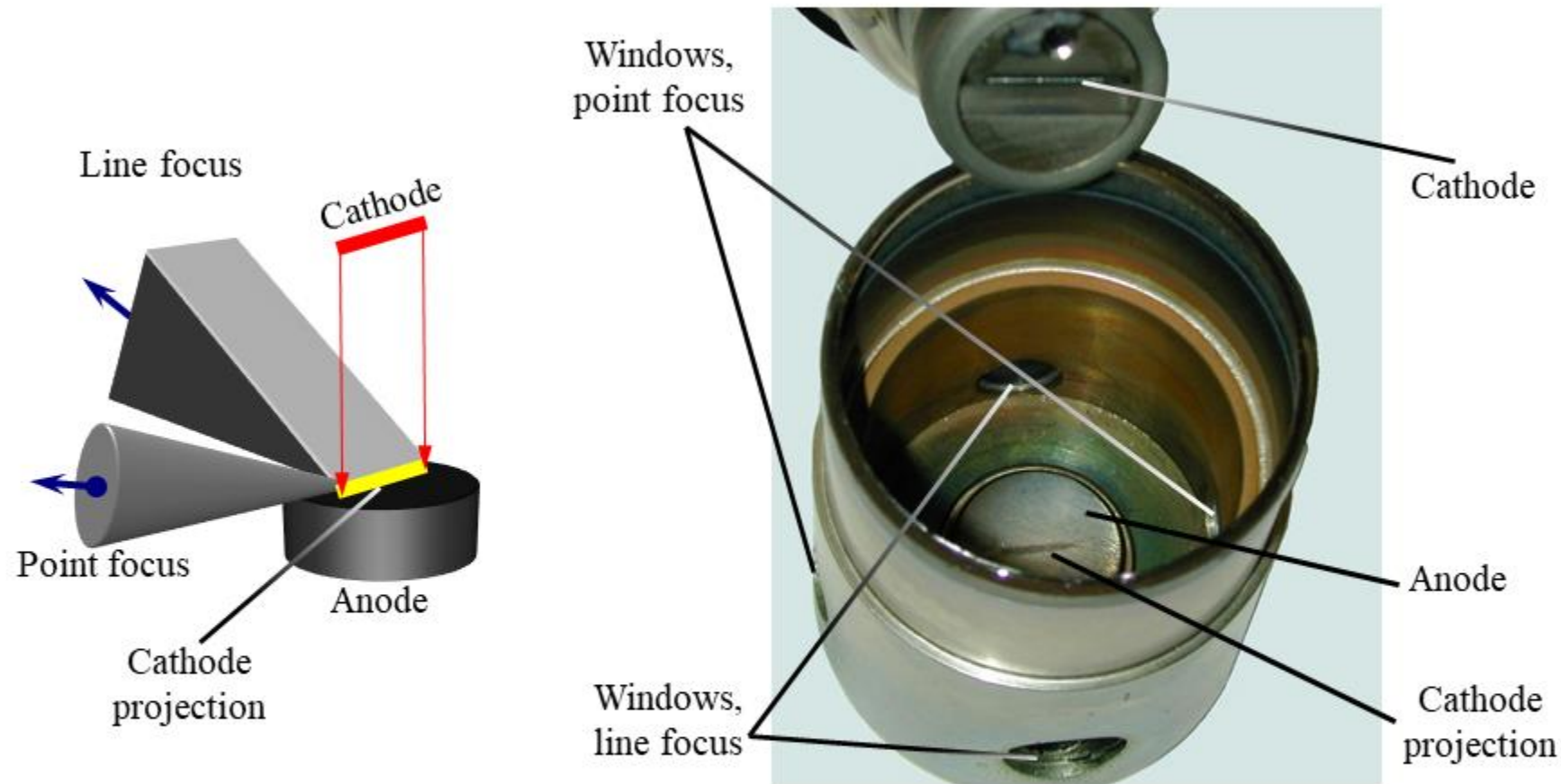


Figure 6.5. The schematic explaining the appearance of two different geometries of the X-ray focus in a conventional sealed X-ray tube (*left*) and the disassembled tube (*right*). The photo on the right shows the metallic can with four beryllium windows, two of which correspond to line- and two to point-foci. The surface of the anode with the cathode projection

is seen inside the can (*bottom, right*). What appears as a scratch on the surface of the anode is the damage from the high intensity electron beam and a thin layer deposit of the cathode material (W), which occurred during the lifetime of the tube. The cathode assembly is shown on top, right.

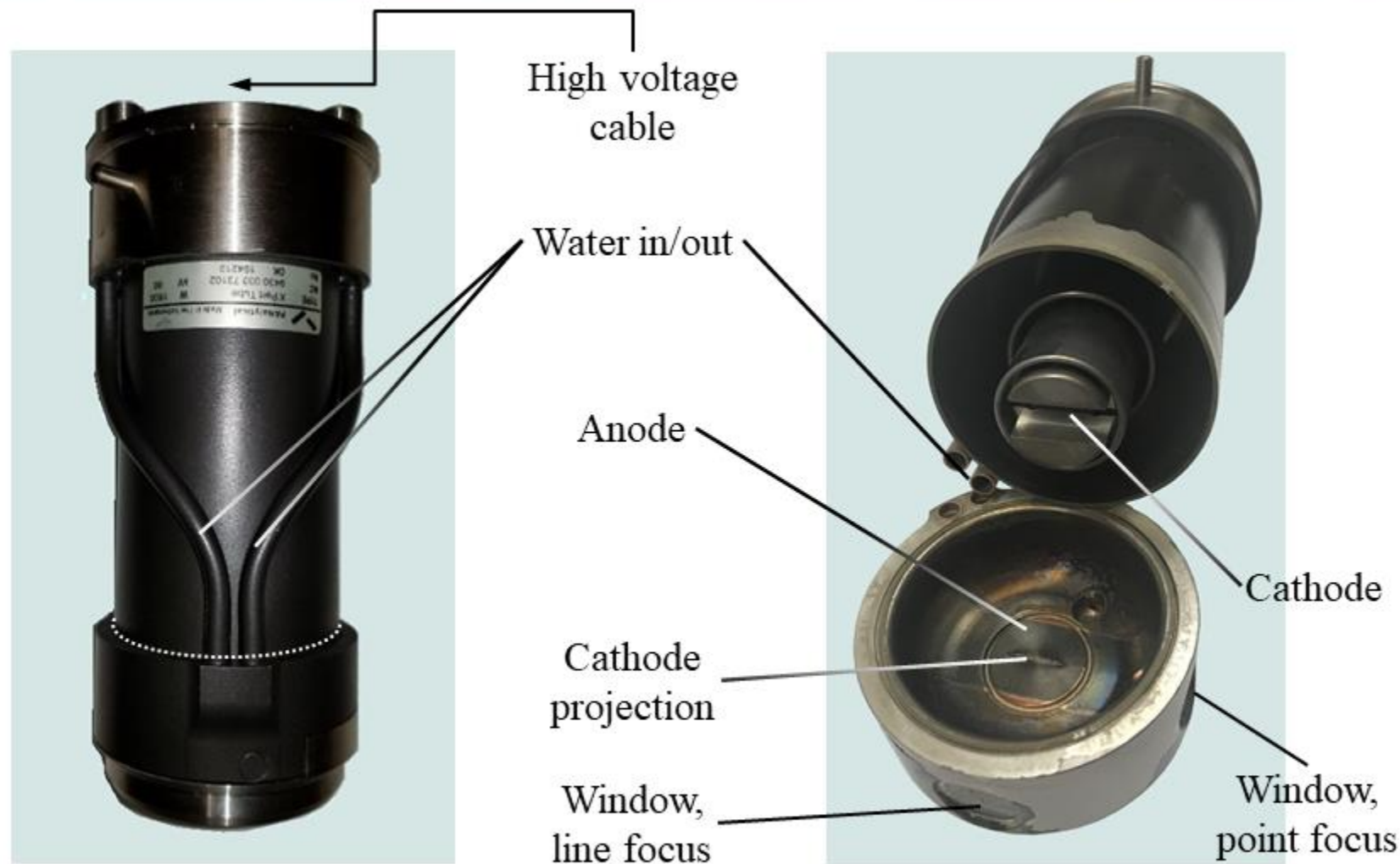


Figure 6.6. Overall view of a sealed all-metal Malvern Panalytical X'Pert X-ray tube with copper anode rated to 60 kV and maximum input power of 1.8 kW(*left*). The same tube, sliced along the white dotted line seen on the left, illustrating the cathode, the anode coated with W film, the projection of the cathode visible as radiation damage on the surface of the anode, and two windows (*right*). Both the W coating and the radiation damage are the result of prolonged use

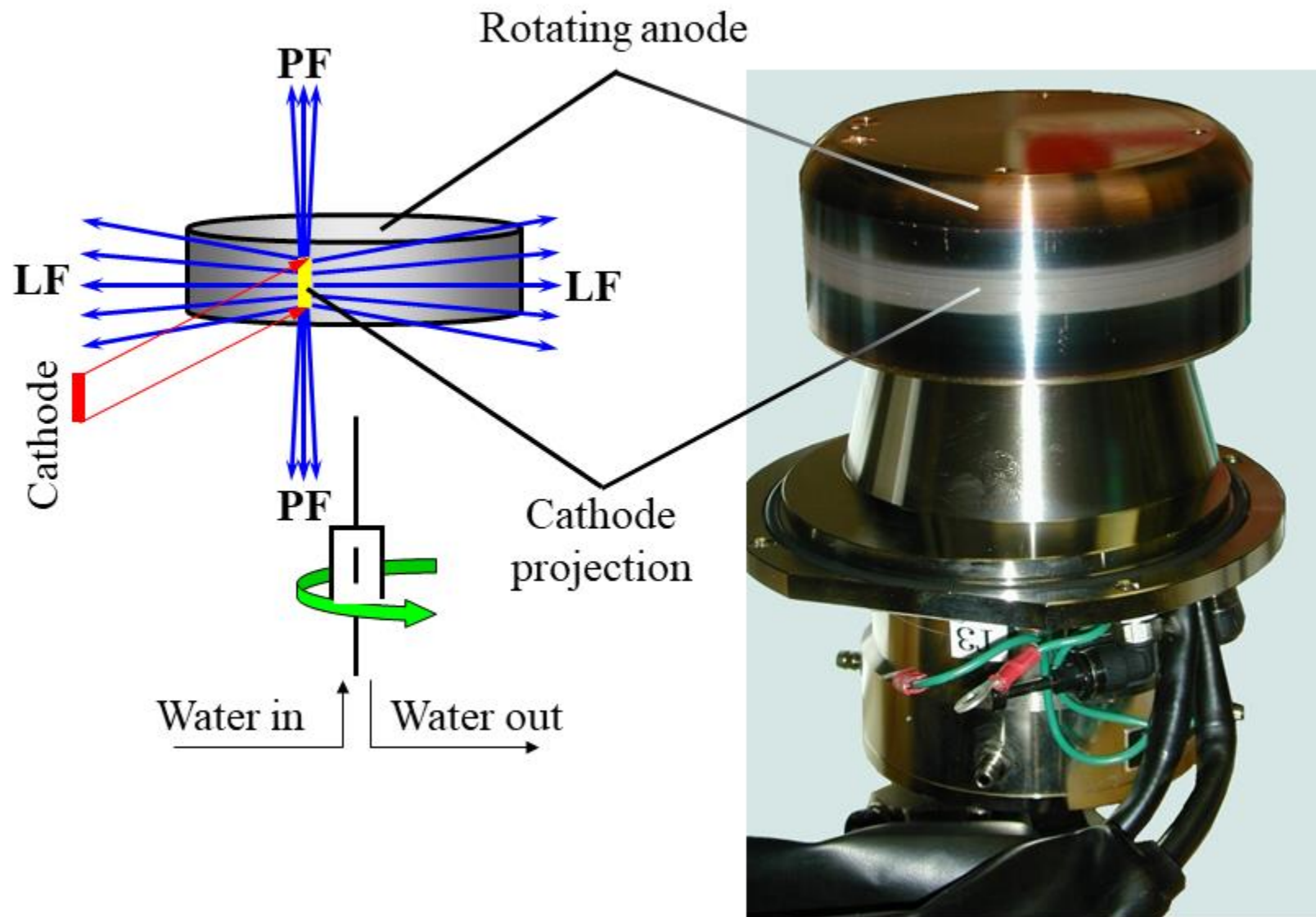


Figure 6.7. The schematic (*left*) and the photograph (*right*) of the direct drive rotating anode assembly employed in a Rigaku TTRAX powder diffractometer. **PF** is point focus and **LF** is line focus. The trace seen on the anode surface on the right is surface damage caused by high-energy electrons bombarding the target and a thin layer deposit of the filament material (W), which occurred during anode operation.

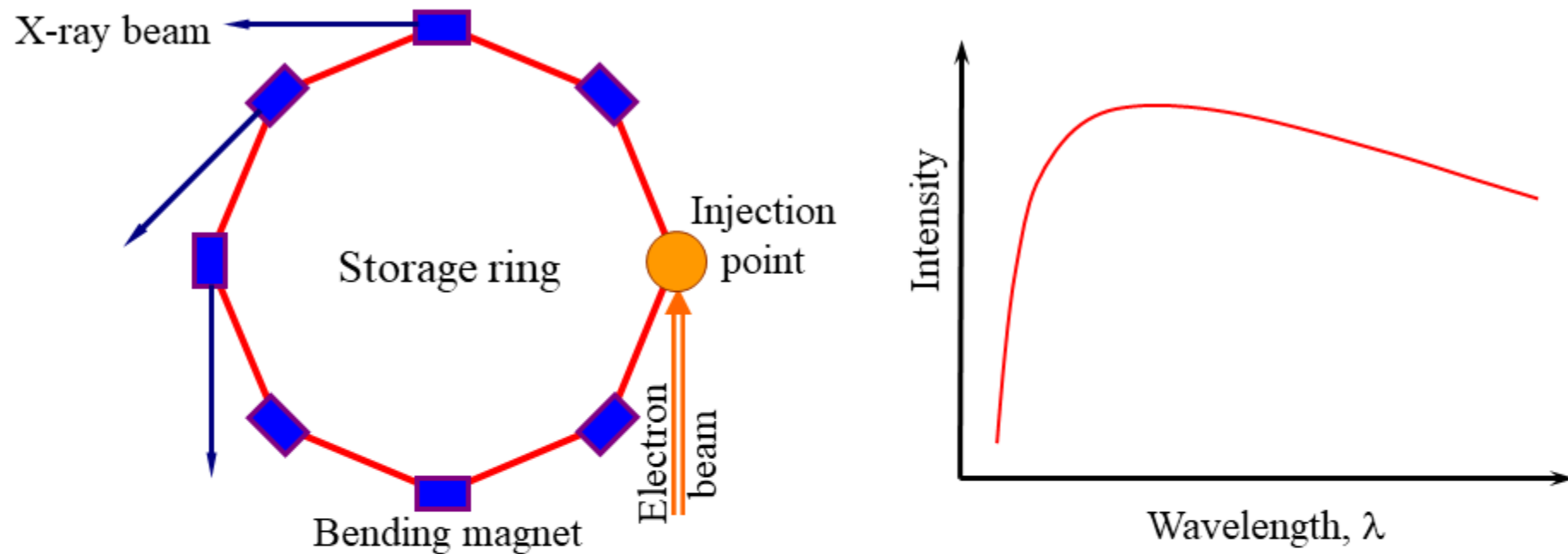
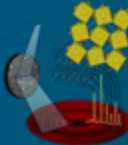


Figure 6.8. Schematic diagram of a synchrotron illustrating X-ray radiation output from bending magnets that can be enhanced by wigglers. Quasi-monochromatic X-rays can be obtained with undulators. Electrons must be periodically injected into the ring to replenish losses that occur during normal operation. Unlike in conventional X-ray sources, where both the long- and short-term stability of the incident photon beam are controlled by the stability of the power supply, the X-ray photon flux in a synchrotron changes with time: it decreases gradually due to electron losses, and then periodically and sharply increases when electrons are injected into the ring.

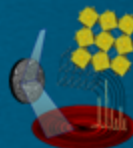


Table 6.2. Comparison of three types of radiation used in powder diffraction.

	X-rays (conv./synch.)	Neutrons	Electrons
Nature	Wave	Particle	Particle
Medium	Atmosphere	Atmosphere	High vacuum
Scattering by	Electron density	Nuclei and magnetic spins of electrons	Electrostatic potential
Scattering function	$f(s) \propto Z^a$	f is constant at all s	$f(s) \propto Z^{1/3},^b$
Wavelength range, λ	0.5–2.5/0.1–10 Å	~1 Å	0.02–0.05 Å
Wavelength selection	Fixed, ^c $K\alpha$, ^b /variable	Variable ^c	Variable ^c
Focusing	None		Magnetic lenses
Lattice image	Reciprocal		Direct, reciprocal
Direct structure image	No		Yes
Applicable theory	Kinematical		Dynamical
Use to determine structure	Relatively simple		Very complex

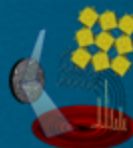


Table 6.3. Selected characteristics of the most common detectors using Cu K α radiation.

Property Detector	Linearity loss at 40,000 cps ^a	Proportionality	Resolution for Cu K α	Energy per event (eV)	No. of events ^b
Scintillation	<1%	Very good	45%	350	23
Proportional	<5%	Good, but fails at high photon flux	14%	26	310
Solid state	Up to 50%	Pileup in mid-range	2%	3.7	2,200

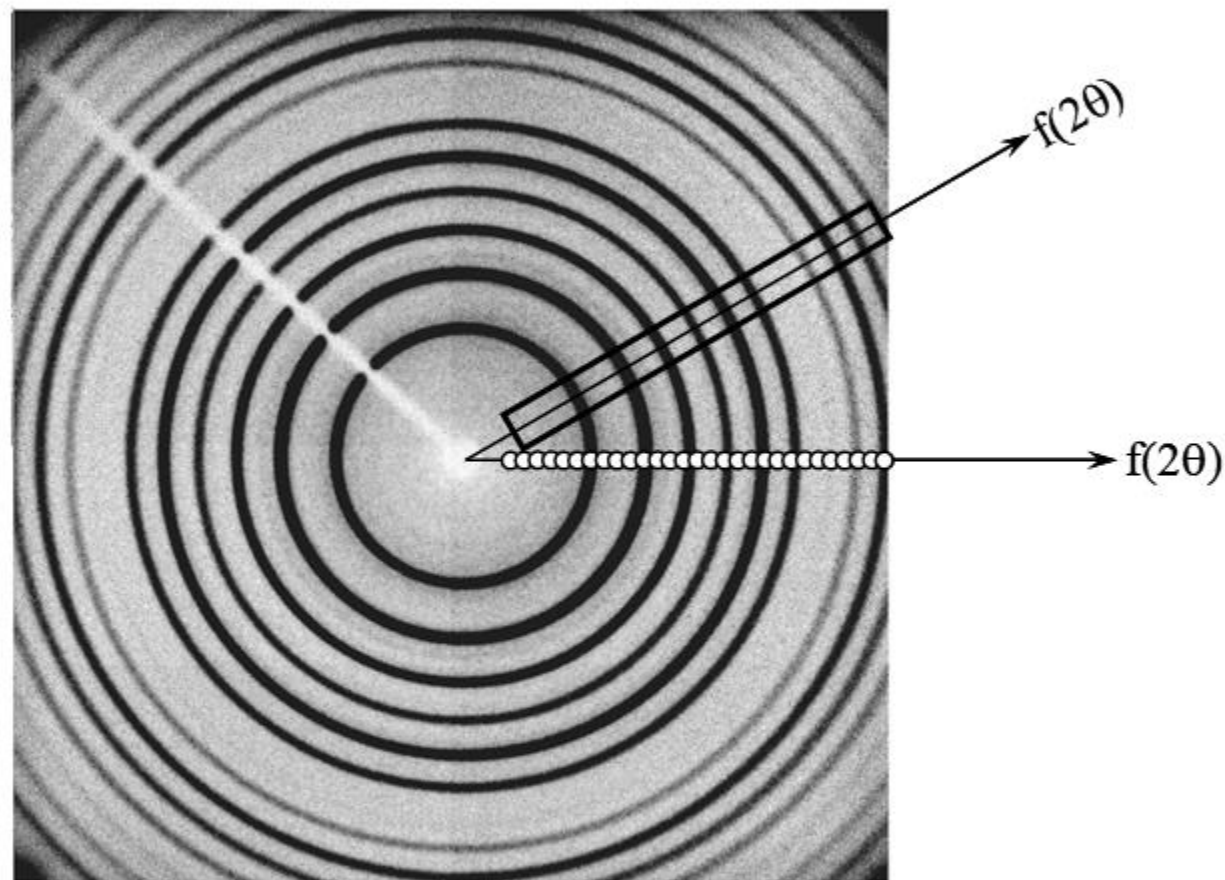


Figure 6.9. The schematic explaining the difference between point (a set of *discrete dots*), line (represented by a *solid rectangle*) and area (depicted as *the entire picture*) detectors used in modern powder diffractometry. The faint trace extending from the center of the image to the upper left corner is the shade from the primary beam stop. The Bragg angle is zero at the center of the image and it increases along any radial line as shown by the *two arrows* (also see Figure 8.4).

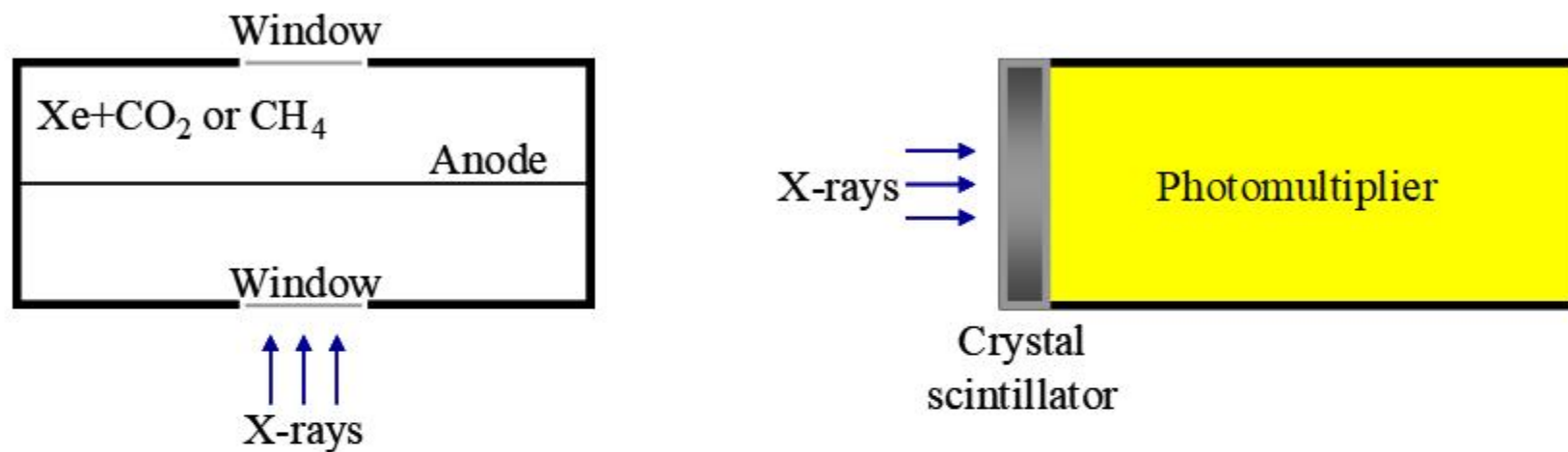


Figure 6.10. The schematics of the gas proportional counter (*left*) and the scintillation (*right*) detectors of X-rays.

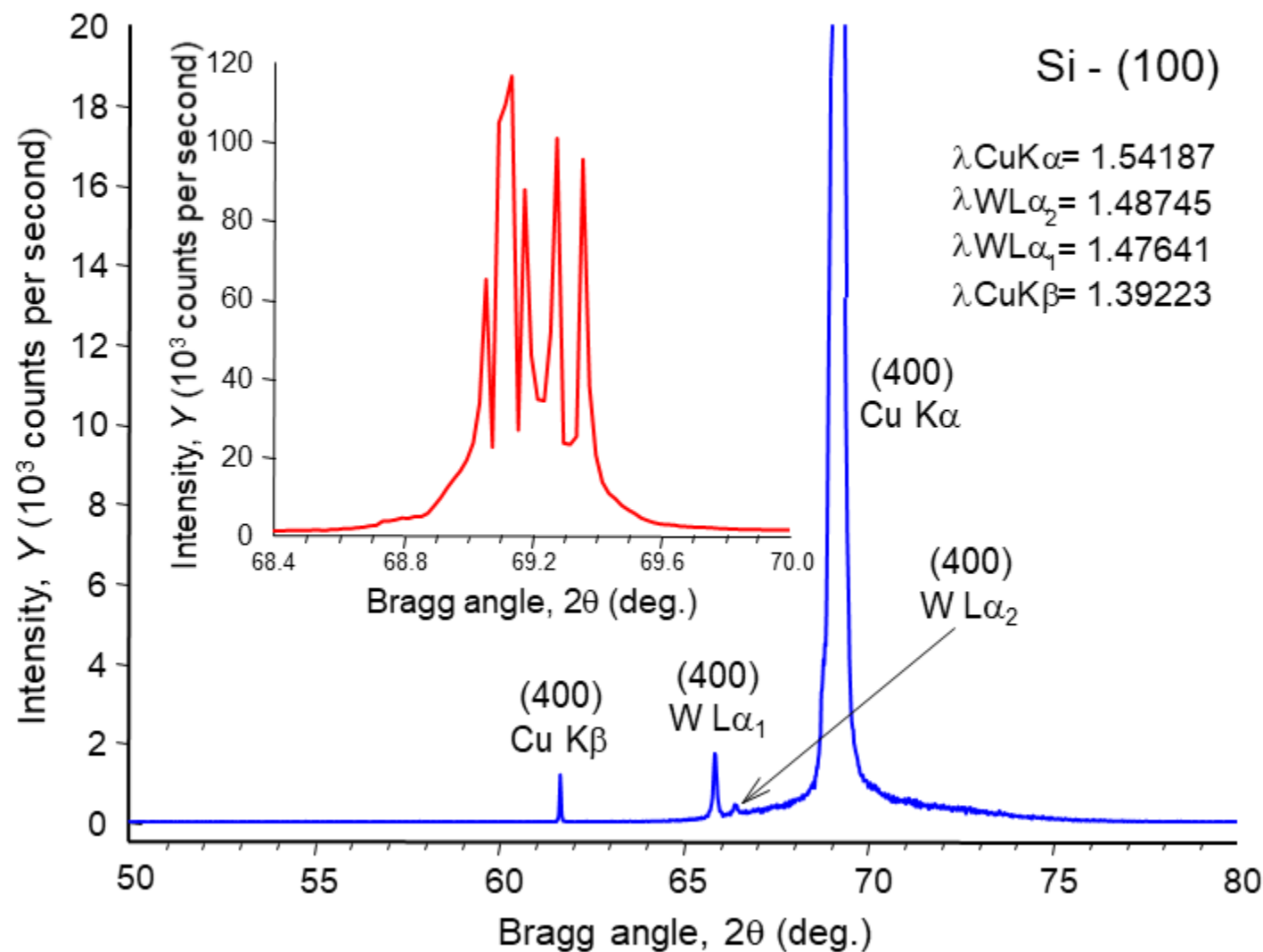
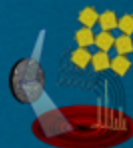


Figure 6.11. The X-ray diffraction pattern collected from a single crystalline Si-wafer in the reflecting position with the [100] direction perpendicular to its surface using a powder diffractometer equipped with the thermoelectric cooled Si(Li) solid-state detector. The inset shows multiple random spikes for the (400) Cu K α peak when photon flux exceeds $\sim 20,000$ cps due to the non-linearity of the detector. The additional Bragg peaks are marked with the corresponding characteristic wavelengths.

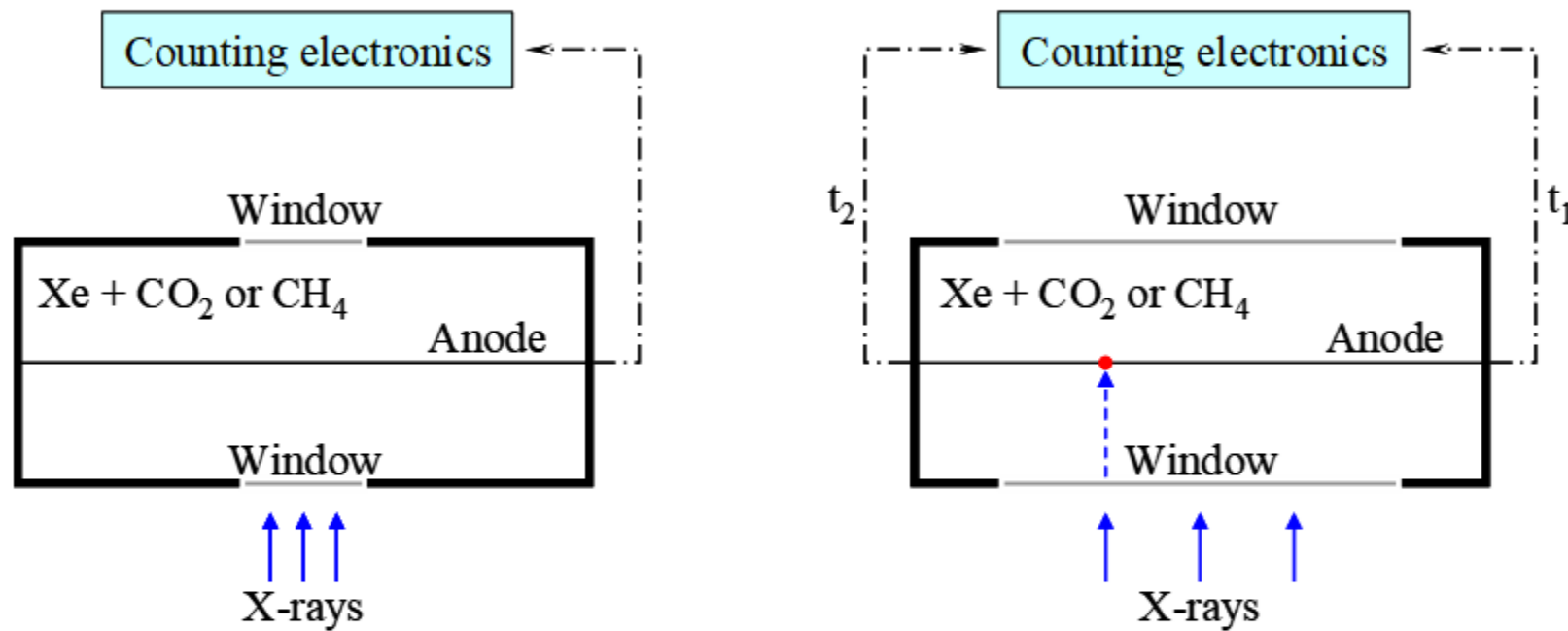
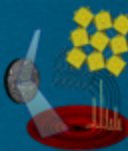


Figure 6.12. The schematic compares the conventional gas proportional detector (*left*), where the signal is collected on one side of the wire anode, with the position-sensitive detector (*right*), where signals are measured on both sides of the wire anode. The position of the electron discharge (represented by a red dot) is determined by the counting electronics based on the time difference between t₁ and t₂ when the two signals are recorded.

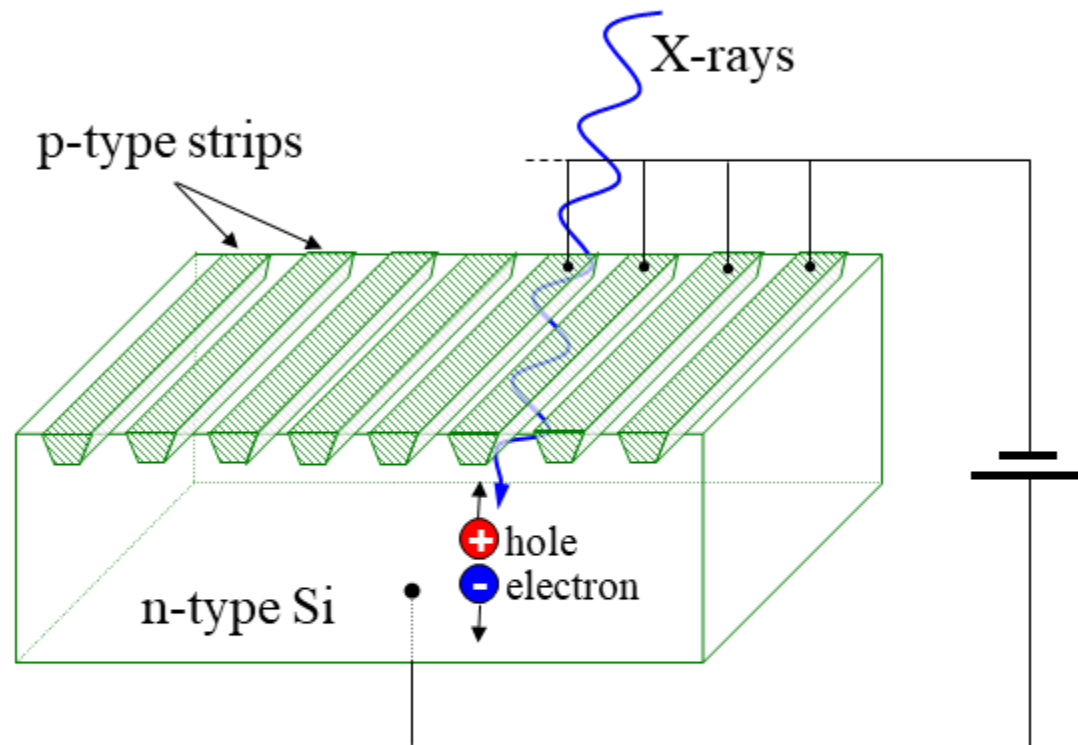
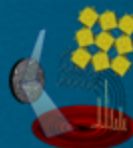


Figure 6.13. The schematic of a strip detector

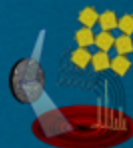


Table 6.4. Qualitative comparison of the most common area detectors.

Parameter	CCD	IPD	MWD	PAD
Active area size	Small	Large	Small	Large
Readout time	Medium	Long	Short	Near 0
Counting rate	High	High	Low	High
Dynamic range	Medium	High	Medium	High
Spatial resolution	High	Low	Low	High