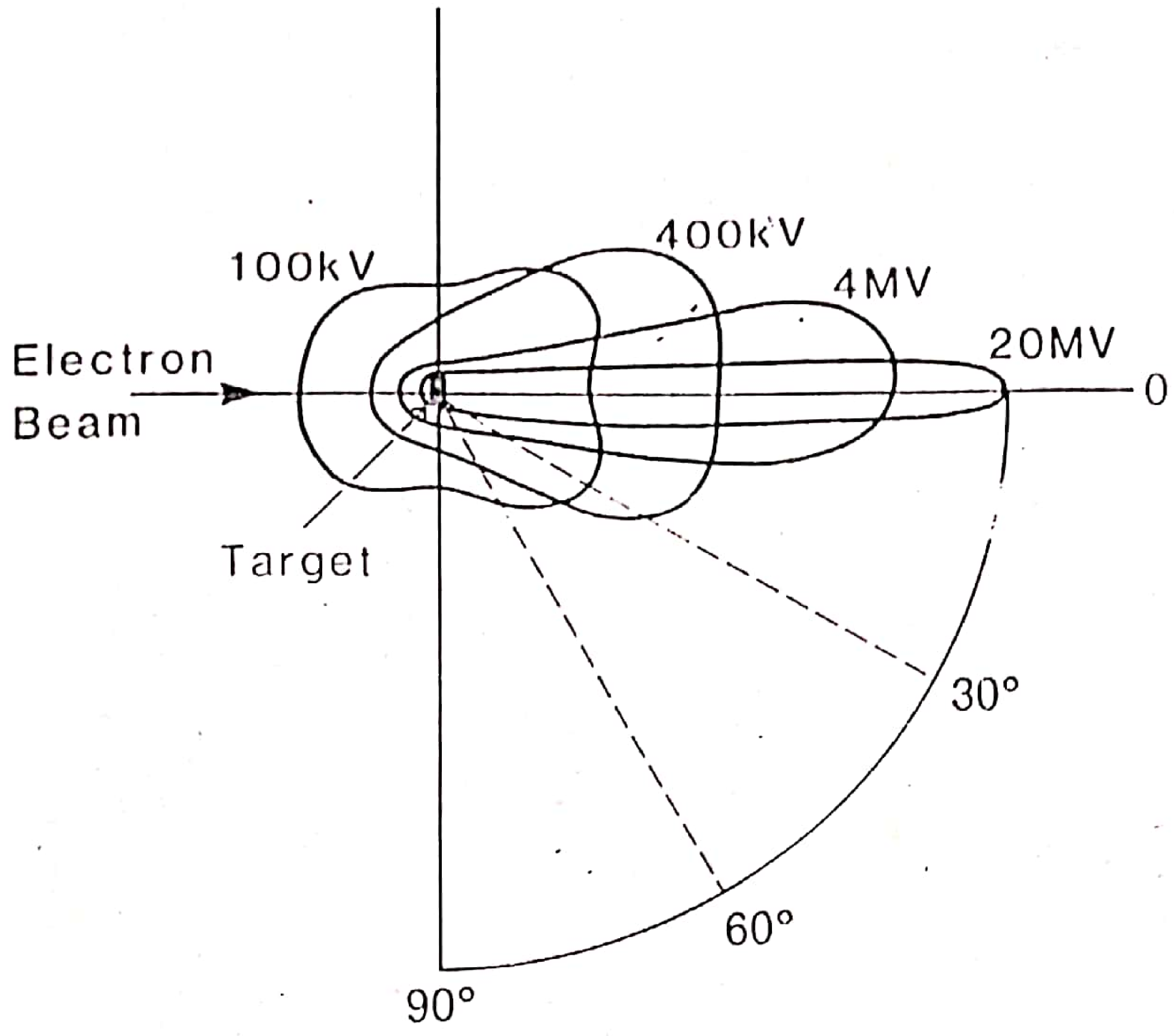

Figure 3.7. Schematic illustration of spatial distribution of x-rays around a thin target.

x-rays to the input energy deposited by electrons. It can be shown (1, 2) that:

$$\text{Efficiency} = 9 \times 10^{-10}\, ZV$$

where V is tube voltage in volts. From the above equation it can be shown that the efficiency of x-ray production with tungsten target ($Z = 74$) for electrons accelerated through 100 kV is less than 1%. The rest of the input energy (~99%) appears as heat.

B. Characteristic X-rays

Electrons incident on the target also produce characteristic x-rays. The mechanism of their production is illustrated in Fig. 3.8. An electron, with kinetic energy E_0, may interact with the atoms of the target by ejecting an orbital electron, such as a K, L, or M electron, leaving the atom *ionized*. The original electron will recede withdraw from the collision with energy $E_0 - \Delta E$, where ΔE is the energy given to the orbital electron. A part of ΔE is spent in overcoming the binding energy of the electron and the rest is carried by the ejected electron. When a vacancy is created in an orbit, an outer orbital electron will fall down to fill that vacancy. In so doing, the energy is radiated in the form of electromagnetic radiation. This is called characteristic radiation, *i.e.* characteristic of the atoms in the target and of the shells between which the transitions took place. With higher atomic number targets and the transitions involving inner shells such as K, L, M, and N, the characteristic radiations emitted are of high enough energies to be considered in the x-ray part of the elctromagnetic spectrum. Table 3.1 gives the major characteristic radiation produced in a tungsten target.

It should be noted that, unlike bremsstrahlung, characteristic radiation or x-rays are emitted at discrete energies. If the transition involved an electron descending from the L shell to the K shell, then the photon emitted will have energy $h\nu = E_K - E_L$, where E_K and E_L are the electron-binding energies of the K shell and the L shell, respectively.

The threshold energy that an incident electron must possess in order to first strip an electron from the atom is called *critical absorption energy*. These energies for some elements are given in Table 3.2.

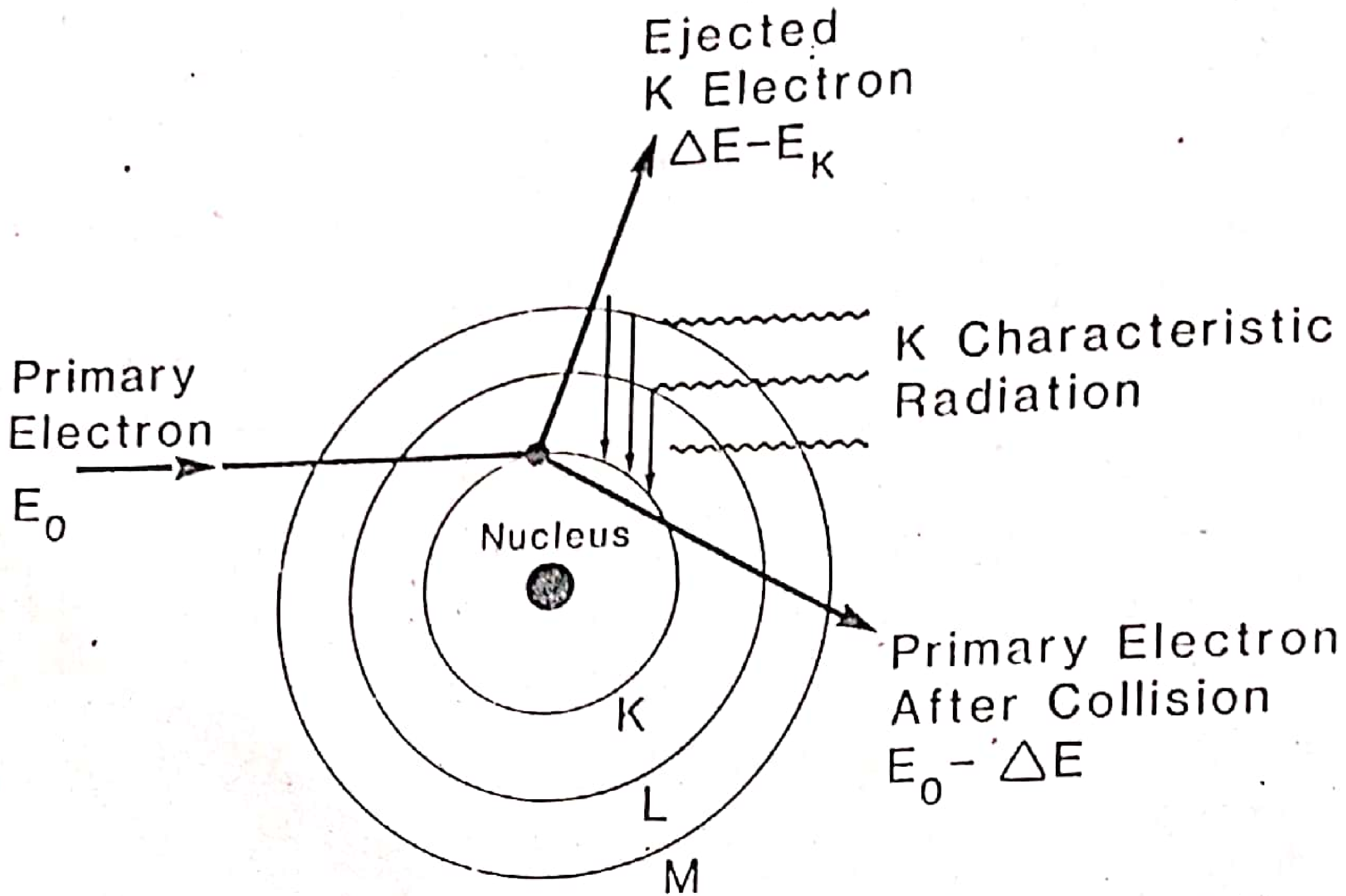

Figure 3.8. Diagram to explain the production of characteristic radiation.

Table 3.1.
Principal characteristic x-ray energies for tungsten

	Lines	Transition	Energy (keV)
K Series	$K\beta_2$	$N_{III} - K$	69.09
	$K\beta_1$	$M_{III} - K$	67.23
	$K\alpha_1$	$L_{III} - K$	59.31
	$K\alpha_2$	$L_{II} - K$	57.97
L Series	$L\gamma_1$	$N_{IV} - L_{II}$	11.28
	$L\beta_2$	$N_V - L_{III}$	9.96
	$L\beta_1$	$M_{IV} - L_{II}$	9.67
	$L\alpha_1$	$M_V - L_{III}$	8.40
	$L\alpha_2$	$M_{IV} - L_{III}$	8.33

Data from *Radiological Health Handbook* (4).

Table 3.2.
Critical absorption energies (keV)

	Element										
	H	C	O	Al	Ca	Cu	Sn	I	Ba	W	Pb
Level $Z =$	1	6	8	13	20	29	50	53	56	74	82
K	0.0136	0.283	0.531	1.559	4.038	8.980	29.190	33.164	37.41	69.508	88.001
L				0.087	0.399	1.100	4.464	5.190	5.995	12.090	15.870

Data from *Radiological Health Handbook* (4).