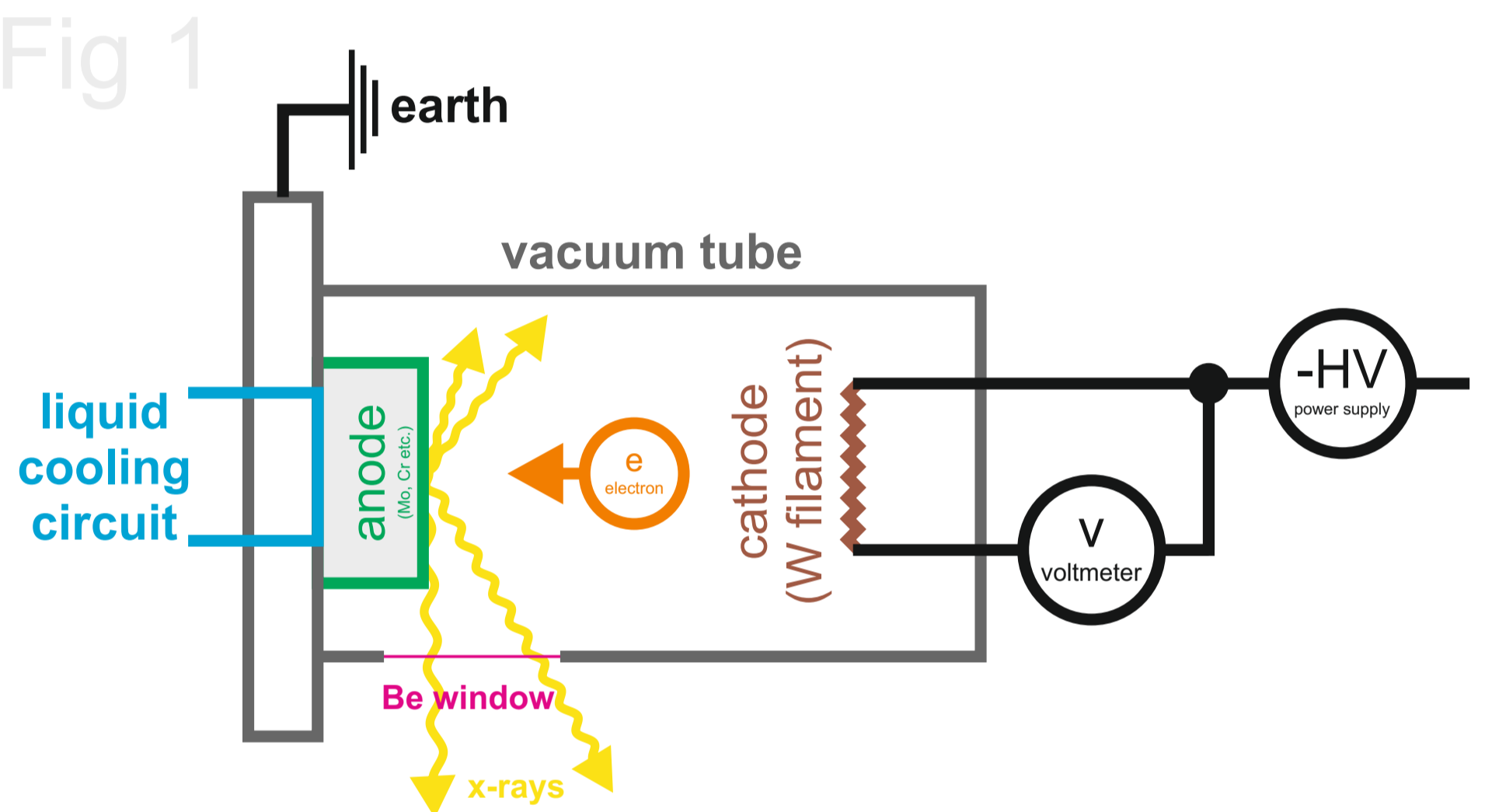# Principles of X-ray Flourescence in the Itrax Core Scanner

X-Ray Beam Generation

X-rays are generated using a grounded-anode type x-ray tube (figure 1). An electrical current heats a Tungsten filament, which produces electrons by thermionic effect. The high voltage potential between the cathode (negatively charged) and the anode (ground state) causes electrons to be accelerated towards the anode.

Electrons colliding with the cathode accelerate other electrons, ions and nuclei in the anode, and a small amount of the energy generated is emitted as x-rays; the majority of the energy is released as heat, necessitating an efficient cooling system for the cathode.

Fig 1

earth

vacuum tube

liquid cooling circuit

anode (Mo Cr etc)

e electron

cathode (W filament)

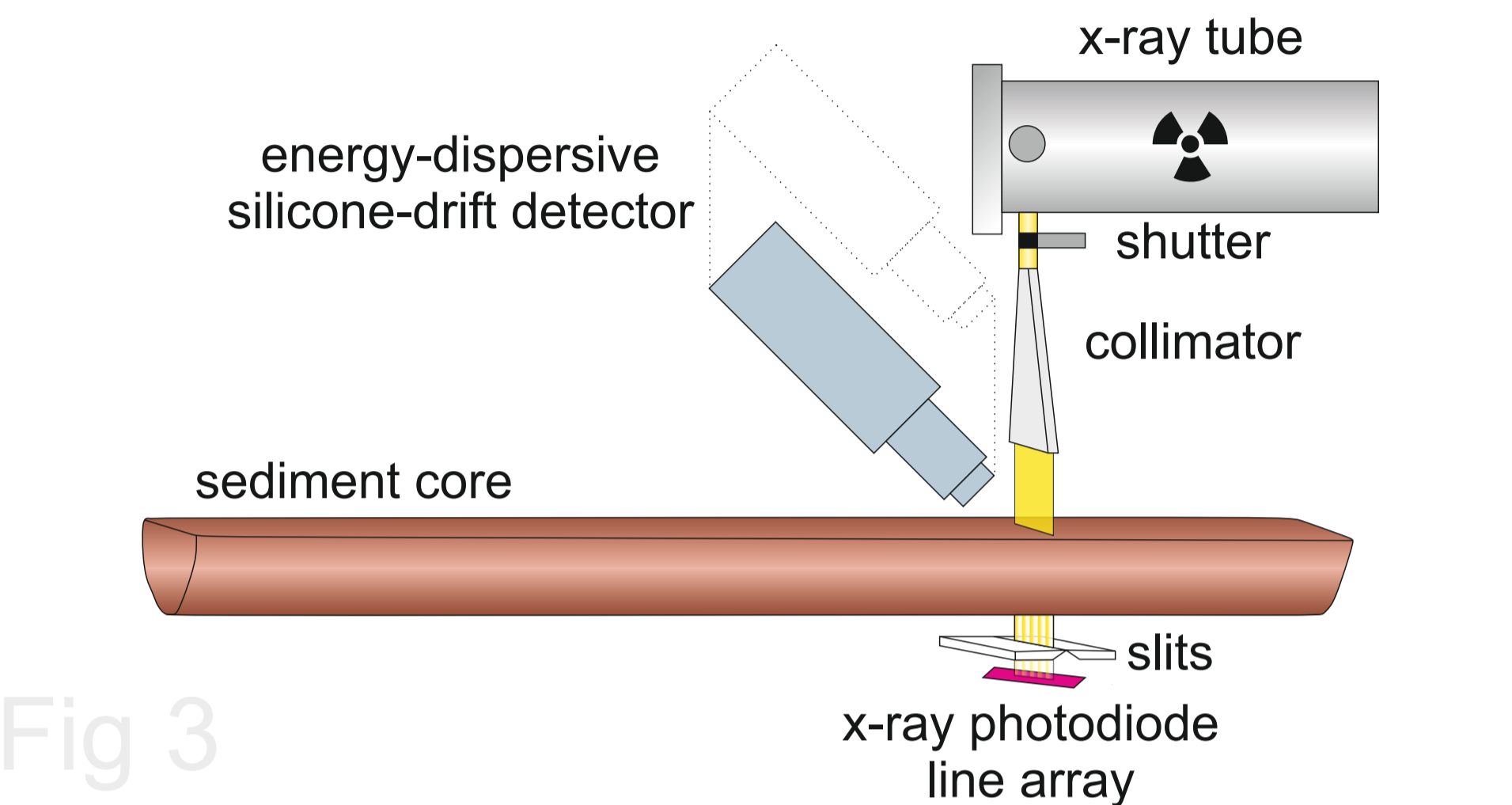-HV power supply

V voltmeter

Be window

x-rays

This x-ray photon generating effect is called the Bremsstrahlung effect (figure 2). Bremsstrahlung radiation has a broad, continuous energy spectrum, with the exact profile dependent on the voltage at which the tube is operated. The characteristic K-lines of the anode material are superimposed on this spectrum.

The x-ray photons escape via a Beryllium window, via a shutter, into a capillary waveguide that collimates the beam into an aligned beam approximately 200 μm wide and 20 mm long (figure 3).

Fig 2

intensity

40 KeV
30 KeV
20 KeV

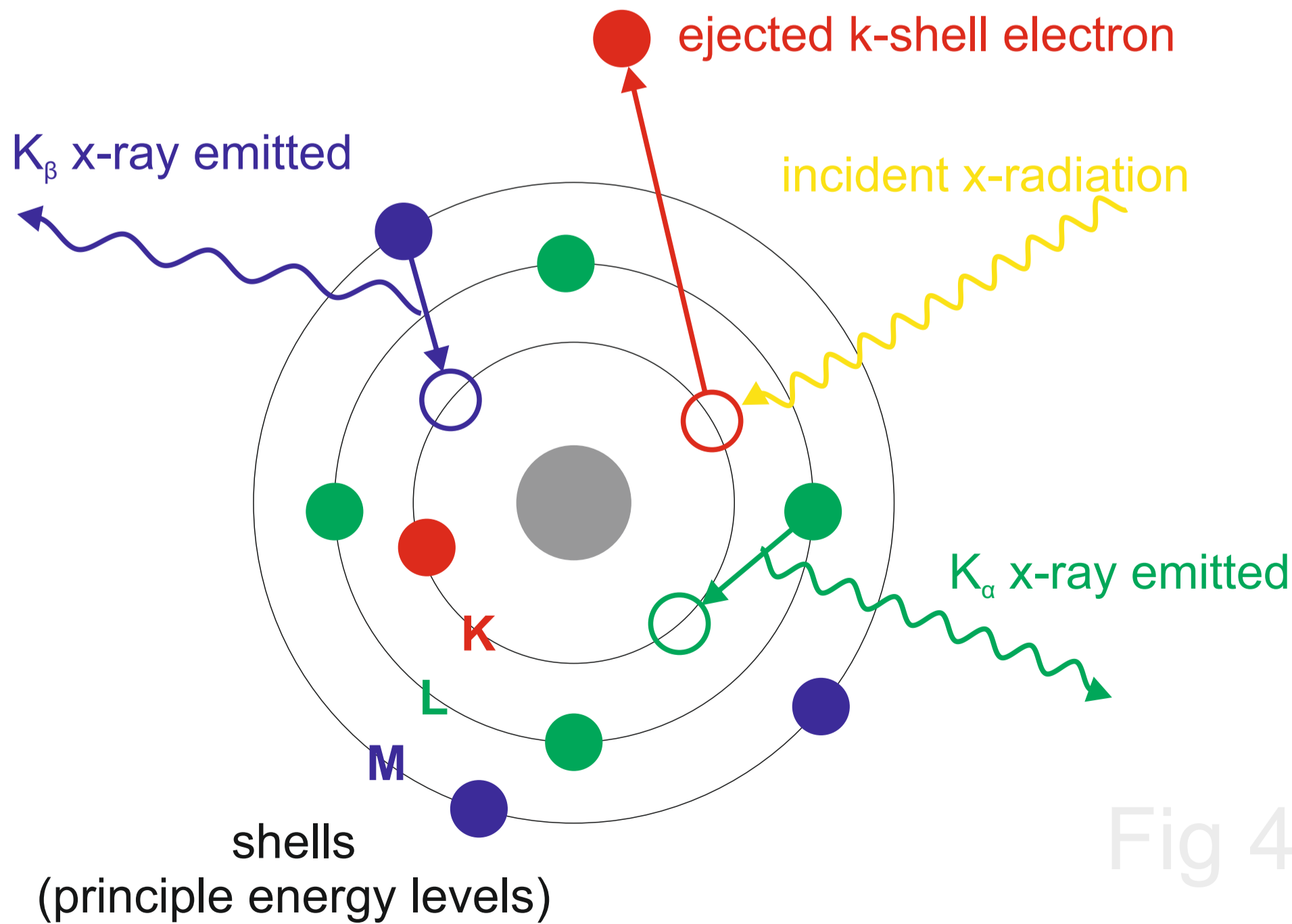Anode K_α
Anode K_β
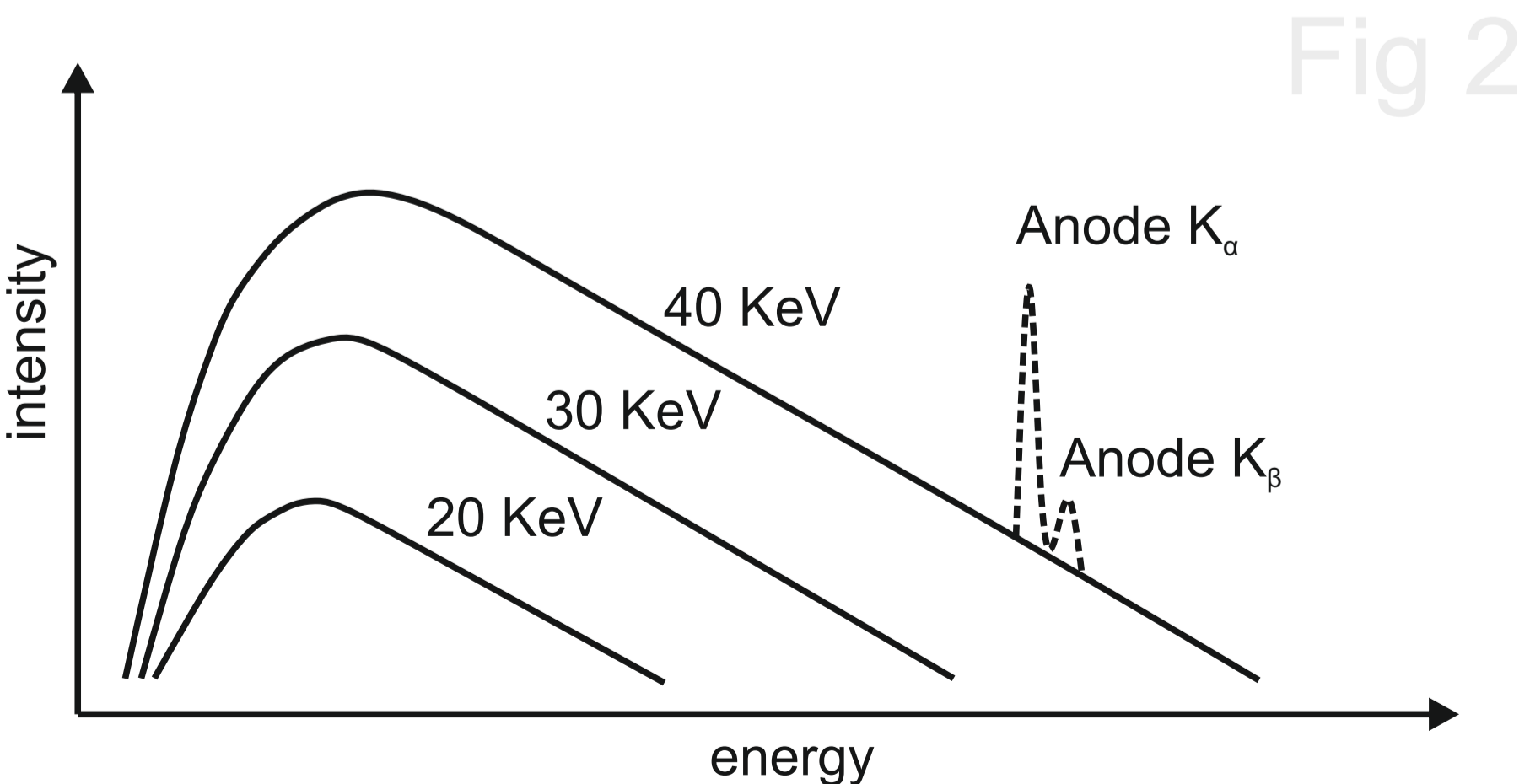
energy

X-Ray Fluorescence

A beam of x-ray photons is directed at the sample to ionise it and produce characteristic fluorescence (figure 3). The size of the peak in the characteristic energies of different elements are used to infer the elemental composition of the sample.

x-ray tube

energy-dispersive silicone-drift detector

shutter

collimator

sediment core

slits

Fig 3

x-ray photodiode line array

Incident radiation can ionise an atom if it has an energy greater than the ionization energy of that orbital for that atom (figure 4). Where inner electrons are expelled, the atom becomes unstable and electrons in lower energy orbitals fill the electron hole. In making this transition energy is released in the form of a photon with an energy equal to the energy difference between the orbitals. There are a limited number of possible transitions. The material will thus emit radiation that is characteristic of the atoms present.

The x-ray beam is also directed at a photodiode array to produce a radiographic image of the core. Slits are used to improve the resolution to greater than that of the beam width (200 μm).

ejected k-shell electron

K_β x-ray emitted

incident x-radiation

K_α x-ray emitted

K
L
M

shells (principle energy levels)

Fig 4

Elemental Characterisation

Each element has a different electron configuration, and thus a different spectrum of characteristic energies. There are a limited number of possible transitions. The main transitions are from L-K and are referred to as K_α; and an M-K transition K_β, but there are also L and M lines for other possible transitions.

Some lines are actually doublets, with the notation taking the form $K_{\alpha 1}$, $K_{\alpha 2}$ etc., due to the spin-orbit interaction energy between the electron spin and orbital momentum (for K_α, of the 2p orbital), but for all but the heaviest elements energy dispersive spectroscopy is unable to resolve the doublet.

The peaks of characteristic energies must be separated from the radiation generated from the x-ray beam used to excite the sample. The peak areas can be used as a dimension-less expression of the concentration of a particular element in a sample.

There are a range of emperical and theoretical (fundamental parameter) based methods for calibrating peak area data into quantitative estimates of elemental composition.

Fig 5

log intensity

Fe K_α
Fe K_β

Mo inc
Mo coh
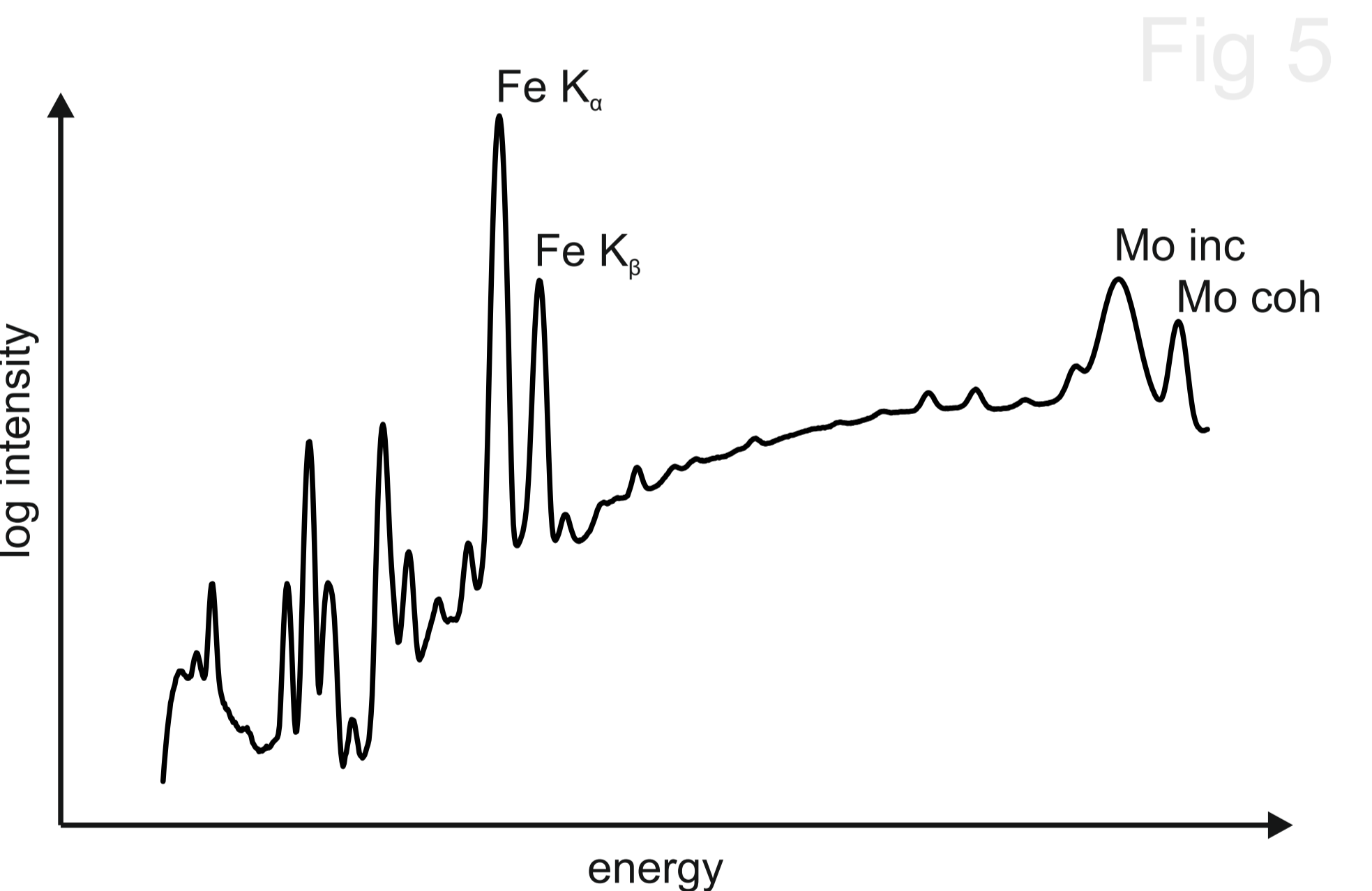
energy

Rayleigh (elastic) scatter occurs where the direction of propagation of a photon changes, but its kinetic energy is conserved. In this context, it can be identified at the characteristic energy of the x-ray tube anode. This is referred to as coherent scatter in figure 5.

Compton (inelastic) scatter occurs where photon of the x-ray beam interacts with the core matter and part of its energy is lost when an electron recoils without producing characteristic radiation. This is referred to as incoherent scatter in figure 5.