

Related topics

Binding energy, photoelectric effect, shell structure of electron shells, characteristic X-ray radiation, γ -spectrometry, X-ray spectral analysis.

Principle and task

The irradiation of strontium (sulphate), cadmium, indium, iodine and barium (chloride) with soft γ -radiations gives rise to K_{α} radiations characteristics of these elements. The X-ray spectra are recorded with a γ -spectrometer consisting of a scintillation counter, a pulse height analyser and a recorder. After calibration of the spectrometer, the Rydberg constant is determined from the energies of the X-ray lines, using Moseley's law.

Equipment

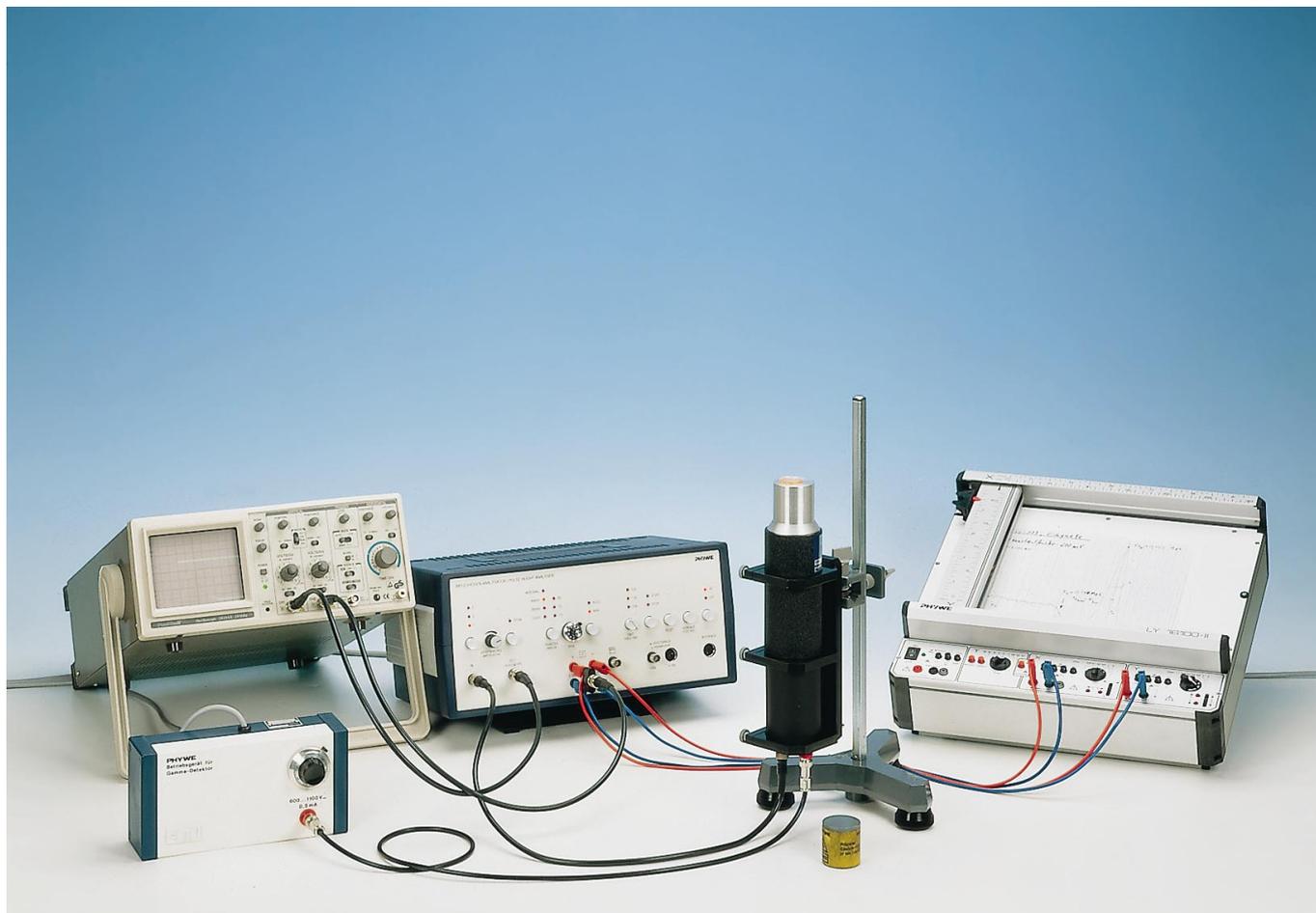
Americium-241 source, 370 kBq	09090.11	1
Source Cs-137, 37 kBq	09096.01	1
Pulse height analyser	13725.93	1
Gamma detector	09101.00	1
Operating unit f. gamma detector	09101.93	1
High-voltage connecting cable	09101.10	1
Oscilloscope, 20 MHz, 2 channels	11454.93	1
xyt recorder	11416.97	1

Absorption plates f. beta-rays	09024.00	1
Support rod -PASS-, square, l 400 mm	02026.55	1
Right angle clamp -PASS-	02040.55	2
Plate holder	02062.00	1
Tripod base -PASS-	02002.55	1
Bottle, wide neck, plastic, 250 ml	33915.00	1
Barium chloride 250 g	30033.25	1
Iodine resublimed 25 g	30093.04	1
Strontium sulphate 100 g	30229.10	1
Screened cable, BNC, l 750 mm	07542.11	3
Connecting cord, 750 mm, red	07362.01	2
Connecting cord, 750 mm, blue	07362.04	2

Problems

1. Calibration of the γ -spectrometer in the low energy range, using the Ba-resonance line of a ^{137}Cs emitter (32 keV) and the γ -line of ^{241}Am at 59.6 keV.
2. Recording of the X-ray fluorescence spectra (K_{α} -lines) of different elements and determination of the corresponding energies.
3. Plotting of the measured X-ray energies according to Moseley's law against $(Z-1)^2$ and determination of the Rydberg constant R_{∞} from the slope of the resulting lines.

Fig. 1: Experimental set-up X-ray fluorescence and Moseley's law.



Set-up and procedure

Set up the detection apparatus as shown in Fig. 1 with the detector and its crystal aligned downwards, ensuring a correct working height (height of the source).

Screen the direct radiation with two superimposed lead plates, 1 mm in thickness.

Position the source as close as possible to the scintillation crystal, noting on the oscilloscope the incidence of any direct radiation.

Place the irradiation specimens in succession at the correct working height in the space in front of the source and the detector.

Adjust the fluorescent radiation to maximum intensity by observation on the oscilloscope.

Adjustment of the pulse height analyser:

Mode of operation	Automatic
Window	5%, only with SrSO ₄ 200 mV
Amplification, coarse	3
Amplification, fine	Right hand stop
Magnifier	Off
Base	10.00
Time interval	0.8 s
Detector voltage	Setting 10.00

Recorder setting:

Measuring range X	0.1 V ($\frac{3.7 \text{ mV}}{\text{cm}}$)
Measuring range Y	1.8 V ($\frac{100 \text{ mV}}{\text{cm}}$)
For SrSO ₄ only	0.36 V ($\frac{20 \text{ mV}}{\text{cm}}$)

In each case mark the zero points of the energy axes. Energy calibration to be carried out with ²⁴¹Am and ¹³⁷Cs (32 keV line only).

Position the Cs source directly against the crystal and the ²⁴¹Am source at a distance of about 18 cm, measuring range Y 1.8 V ($\frac{100 \text{ mV}}{\text{cm}}$).

Theory and evaluation

The binding energies of the electrons are determined by the atomic number of the nucleus. The innermost electrons, known as K-electrons, are the most firmly bound.

If a K-electron is removed from the shell of an atom, this atom will emit K_α radiation during the rearrangement of the planetary electrons.

K_{α1} is the most intense radiation emitted.

The frequency $f_{K\alpha}$ of the K_α radiation is defined by Moseley's Law:

$$f_{K\alpha} = c R_{\infty} \cdot (Z - 1)^2 \cdot 0.75. \quad (1)$$

In which c = the velocity of light ($2.9981 \cdot 10^8 \text{ m/s}$),
 R_{∞} = the Rydberg constant ($1.097 \cdot 10^7 \text{ m}^{-1}$),
 Z = the atomic number.

The soft α-radiation of ²⁴¹Am (59.6 keV) enables characteristic radiations to be generated from a number of elements without the occurrence of interference effects; elements with atomic numbers from about 35 to 69 are suitable for this purpose.

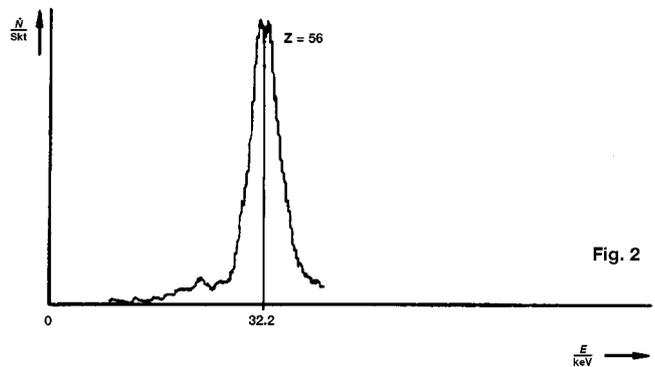


Fig. 2

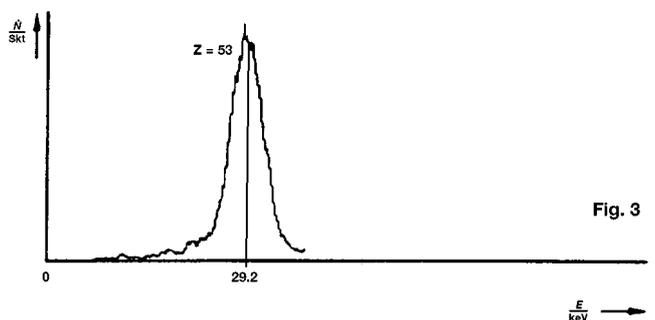


Fig. 3

Figs. 2 to 6 show on a number of measurement examples the spectra of X-ray-fluorescence radiation obtained with barium, iodine, indium (if available), cadmium and strontium. Fig. 7 shows the calibration lines of ¹³⁷Cs and ²⁴¹Am plotted on the same energy scale.

To evaluate these spectra, the energy scale for the energy range in question is calibrated underneath the calibration line of the Cs emitter by linear extrapolation, after which the linear centre points are obtained by geometric means and the corresponding energy values determined.

The resonance line energies shown in the table below were determined in the measurement example

Element	Z	$\frac{E_{K\alpha}}{\text{keV}}$
Sr	38	13.6
Cd	48	23.3
(In)	49	24.3
I	53	29.3
Ba	56	32.2

These energy values have been plotted in Fig. 8 against $(Z-1)^2$, yielding a linear relationship. The slope of the curve is $m = 0.0112 \text{ keV}$.

Interpretation

The ²⁴¹Am photons (59.6 keV) excite by means of a photoelectric effect on K-electrons characteristic X-radiation in the irradiated material, provided that they apply the binding energy of the K-electrons.

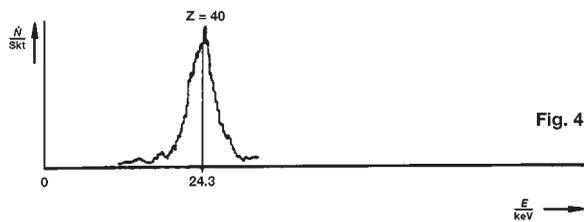


Fig. 4

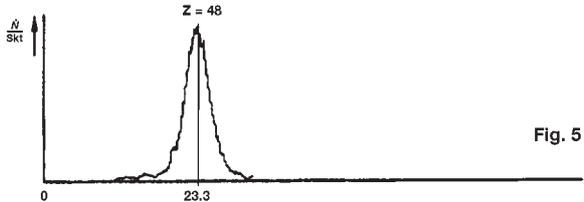


Fig. 5

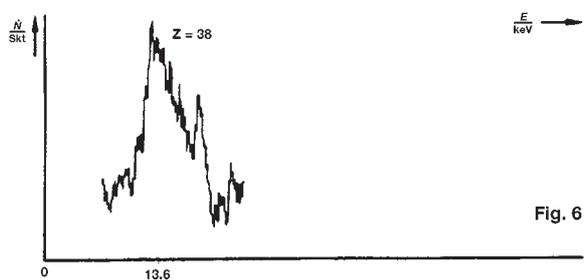


Fig. 6

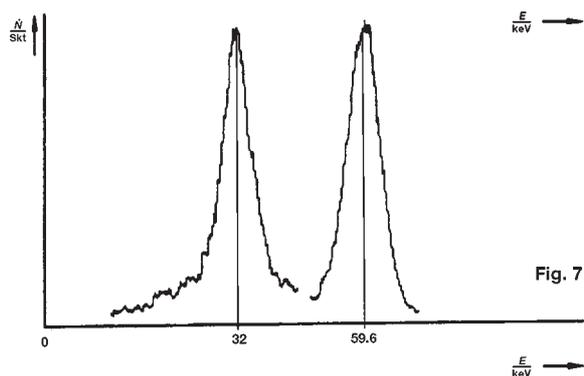


Fig. 7

The energy of the characteristic X-radiation increases on a quadratic scale with the atomic number of the emitter.

Using Moseley's Law (1), we obtain from the slope m in Fig. 8 the following value for the Rydberg constant

$$c \cdot R_{\infty} = m/0.75 h,$$

in which h denotes Planck's quantum of action.

This represents in numerical terms

$$R_{\infty} = 1.20 \cdot 10^7 \text{m}^{-1}$$

which agrees sufficiently well with the value in the literature: $1.097 \cdot 10^7 \text{m}^{-1}$.

Note

Glass or Plexiglas are unsuitable as containers for the chemicals for examination, since they emit an appreciable characteristic fluorescence.

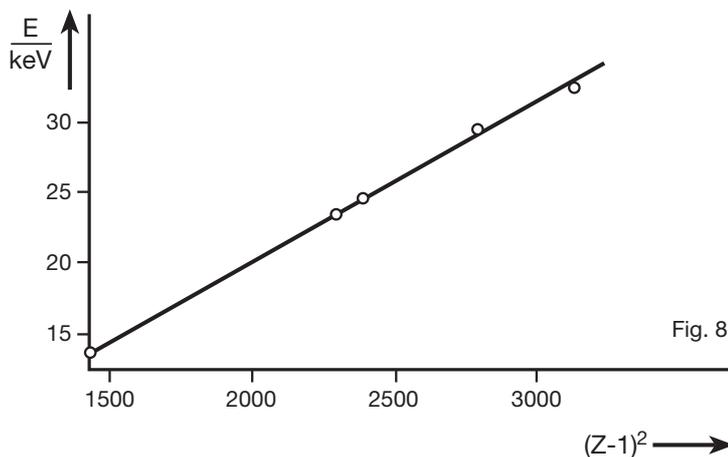


Fig. 8

Fig. 8: Graph of the energy values versus $(Z-1)^2$ as shown in the table above.