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GAMMA-RAY ATTENUATION COEFFICIENT MEASUREMENTS FOR DIFFERENT ROCKS

by

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Abstract

Total gamma-ray attenuation coefficients have been measured in the energy range 0.3—1.8 MeV for the following rocks: gabbro, anorthosite (two types), amphibolite and a sample of ilmenite-magnetite ore. The values obtained were in good agreement with the theoretically evaluated coefficients.

Introduction

As gamma radiation traverses matter there is interaction and the following processes may occur: photoabsorption, scattering and pair formation. The latter process is naturally limited to gamma-ray energies above the threshold energy of 1.022 MeV. The attenuation of gamma rays follows the exponential law

$$I = I_0 e^{-\mu x} \tag{1}$$

where I_0 stands for the initial gamma-ray intensity and I is the intensity of the beam which has traversed the matter. Here μ is the total attenuation coefficient and x the track length in the matter.

Measurements and calculations of the attenuation coefficients for pure elements have been performed by several workers. The total at-

tenuation coefficients for a variety of materials were measured by WIEDENBECK [6] in the energy range between 40 keV and 412 keV. MCGRARY *et al.* [4] measured attenuation coefficients in the energy range of 25 keV to 130 keV for several elements. PARTHASARADHI [5], furthermore, measured attenuation coefficients for five gamma-ray energies between 145 keV and 662 keV in Al, Cu and Pb. Recently CONNER *et al.* [1] have extended the measurements to include even higher gamma-ray energies. For this purpose they used radioactive isotopes yielding gamma rays with energies between 88 keV and 2750 keV.

The theory behind this problem has been discussed in detail by GRODSTEIN [2] and MCGINNIES [3]. They calculated X-ray attenuation coefficients within the range 10 keV — 100 MeV for both pure elements and some chemical coumpounds, such as sodium iodine and calcium phosphate, as well as for some alloys, such as air and concrete.

As can be observed from the above, little effort has been directed towards measuring attenuation coefficients for composite materials. We have therefore determined experimentally the attenuation coefficients for some rocks and compared them with the values obtained by theoretical calculations.

Experimental technique

Fig. 1 contains a schematic representation of the experimental setup for measuring attenuation coefficients. The gamma-ray source is located at the far end of the first collimator. The gamma-ray beam is then narrowly collimated before it enters the sample. After the sample there is a second collimator, to prevent the gamma rays scattered through a small angle from reaching the detector. The collimators

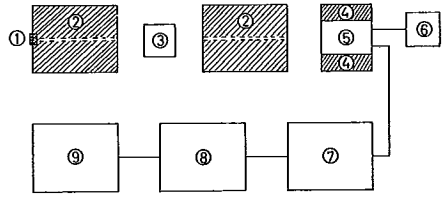

Fig. 1. Block diagram of the experimental setup. 1. Radioactive source, 2. Collimators, 3. Rock sample, 4. Lead shield, 5. Ge(Li)-detector, 6. High voltage supply, 7. Multimode amplifier, 8. Multichannel analyser, 9. Teletype printer.

are made of lead; they are 6 cm long and situated 7.5 cm apart from each other. The diameter of the collimating slot is 5 mm.

For the detection of gamma rays, a 54 cm^3 Ge(Li)-detector in connection with a 400-channel pulse height analyser LP 4840 from Oy Nokia Ab was used. The energy resolution of the detector system was about 4 keV at 1.33 MeV.

Attenuation coefficients were measured for gamma rays in the energy range 0.3—1.8 MeV by utilizing radioactive sources. In Table 1 these sources together with the corresponding gamma-ray energies are listed.

Table 1. List of the standard sources used in the measurements. Included are the gamma-ray energies and half-lifes of the radioactive preparates.

Source	Gamma-ray energy (MeV)	Half-life
^{133}Ba	0.302	10 y
	0.356	
^{22}Na	0.511	2.6 y
^{137}Cs	0.662	30 y
^{54}Mn	0.835	314 d
^{88}Y	0.898	107 d
^{60}Co	1.173	5.26 y
^{22}Na	1.275	2.6 y
^{60}Co	1.332	5.26 y
^{88}Y	1.836	107 d

Samples of cylindrical shape were used in the measurements. The lenghts of the cylinders were about 1.5 cm, 3.5 cm and 5 cm, and their diameter was 2.2 cm. The cylindrical samples were obtained from diamond drill holes.

The multi-channel analyzer was used for recording spectra and the intensities of the gamma-ray lines were obtained from an analysis of the spectra. Measurements with and without samples were performed, and from each measurement the total attenuation coefficient was calculated using the formula

$$\mu = \frac{ln \frac{I_0}{I}}{x} \tag{2}$$

From a series of N measurements the average value was evaluated thus:

$$\bar{\mu} = \frac{1}{N} \sum_{i=1}^{i=N} \mu_i \tag{3}$$

and the standard deviation was calculated from the formula

$$\sigma = \sqrt{\frac{1}{N(N-1)} \sum_{i=1}^{N} (\mu_i - \bar{\mu})^2} \tag{4}$$

Results and discussion

In the present investigation we measured the total attenuation coefficients for gamma rays in the energy region 0.3—1.8 MeV for five samples of rocks occuring in nature. In Table 2 we list the samples together with a notation of their main mineral constituents. In Figs. 2—6 the results of the measurements are presented. These figures also

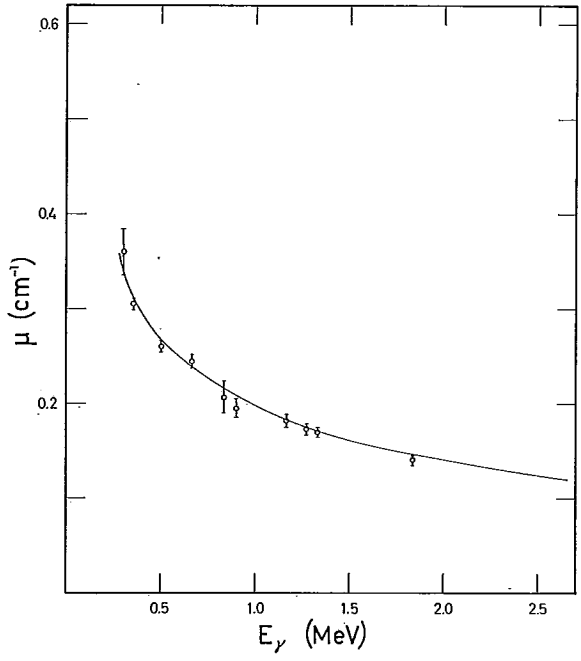

Fig. 2. Total linear attenuation coefficients measured for a gabbro sample. Included is also a theoretically calculated curve based on the estimated chemical composition of the sample.

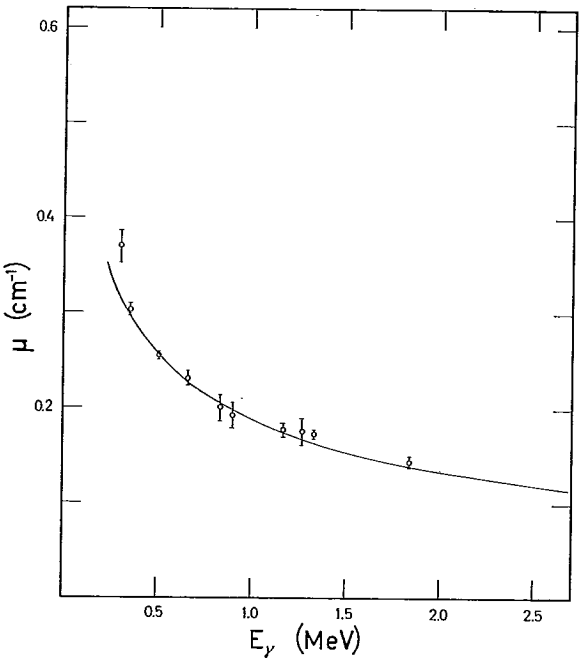

Fig. 3. Total linear attenuation coefficients measured for an anorthosite sample (I). Included is also a theoretically calculated curve based on the estimated chemical composition of the sample.

include the total attenuation coefficients obtained theoretically. These values were calculated using the attenuation coefficients given by GRODSTEIN [2]. The total attenuation coefficient μ for a chemical compound is defined by the equation

$$\frac{\mu}{\varrho} = \sum w_i \frac{\mu_i}{\varrho_i}$$

where w_i is the weight fraction, ϱ_i is the density and μ_i is the total attenuation coefficient of the pure element i. The density of the compound is given by ϱ. The chemical composition of the samples was analysed in more detail than is shown in Table 2, and the μ/ϱ-values were evaluated. As can be seen from Figs. 2—6, the agreement between the measured values and the predicted ones is good.

It may be mentioned that several elements yield almost identical μ_i/ϱ_i-values. Thus the μ/ϱ-value for a certain compound is not af-

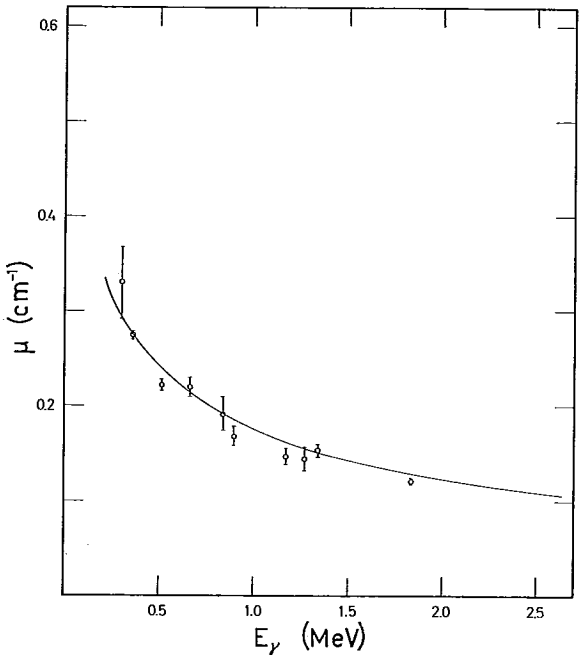

Fig. 4. Total linear attenuation coefficients measured for an anorthosite sample (II). Included is also a theoretically calculated curve based on the estimated chemical composition of the sample.

Table 2. List of the rock samples measured. Their main constituents are also given.

sample	main constituents
gabbro	hornblende, plagioclace
anorthosite	plagioclace, hornblende, titanite
amphibolite	hornblende, ilmenite, sulphurous pyrites
ilmenite-magnetite ore	magnetite, ilmenite, chlorite

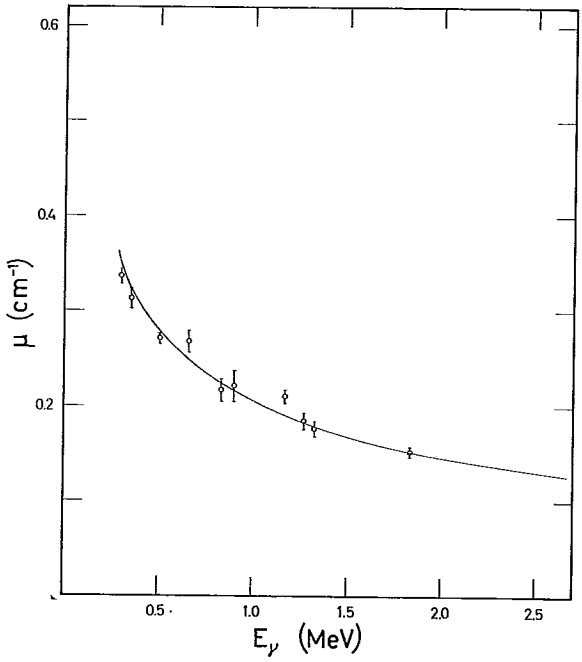

Fig. 5. Total linear attenuation coefficients measured for an amphibolite sample. Included is also a theoretically calculated curve based on the estimated chemical composition of the sample.

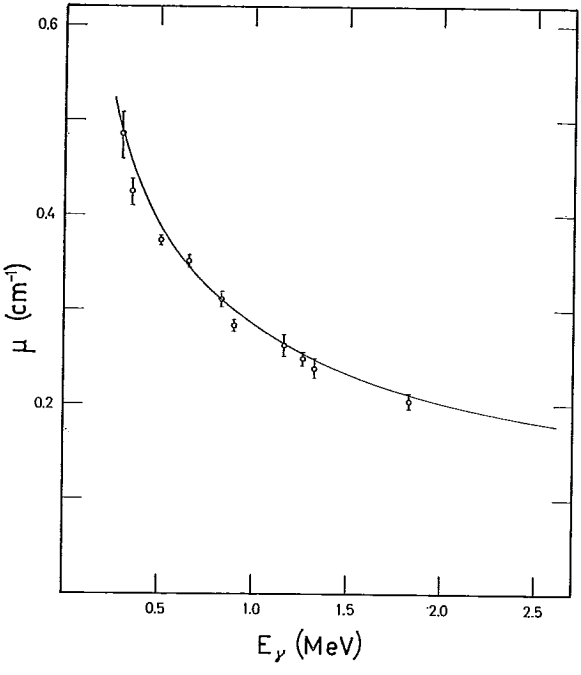

Fig. 6. Total linear attenuation coefficients measured for an ilmenite-magnetite ore sample. Included is also a theoretically calculated curve based on the estimated chemical composition of the sample.

fected by the relative proportions of these elements. A greater effect can be seen when μ is evaluated, for this value depends on the density.

In Fig. 7 we present the values calculated for the total linear attenuation coefficient, μ, for some oxides, and in Fig. 8 the total linear attenuation coefficients for different kinds of hornblende are given (it is assumed that the amphibolite sample consists of 95% of hornblende). The curves are calculated for two hornblende compounds, namely

$$NaCa_2(Mg\ ,\ Fe)_5(Si_7Al\ O_{22})(OH)_2$$

and

$$Ca_2(Mg\ ,\ Fe)_3Al_2(Si_6Al_2O_{22})(OH)_2$$

containing alternatively Mg and Fe. Only small differences in the μ-values can be observed.

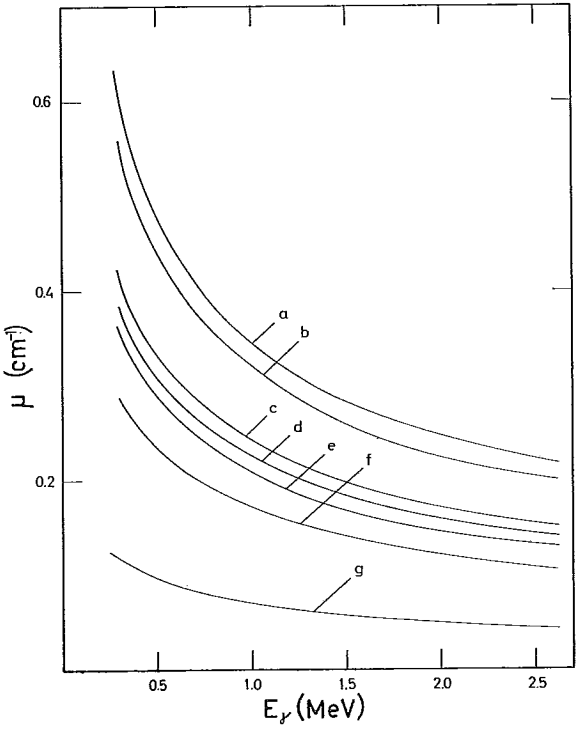

Fig. 7. Theoretically calculated total linear attenuation coefficients for the following oxides: a) FeO, b) Fe_2O_3, c) Al_2O_3, d) MgO, e) CaO, f) SiO_2 and g) H_2O.

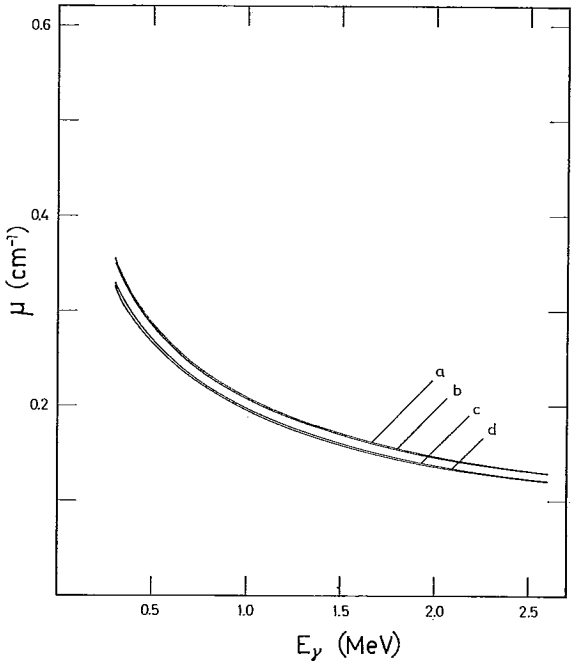

Fig. 8.
Calculated total linear attenuation coefficients for different kinds of hornblende.
a) $NaCa_2Fe_5(Si_7Al\ O_{22})(OH)_2$; $\varrho = 3.33$ g/cm³
b) $Ca_2Fe_3Al_2(Si_6Al_2O_{22})(OH)_2$; $\varrho = 3.30$ g/cm³
c) $Ca_2Mg_3Al_2(Si_6Al_2O_{22})(OH)_2$; $\varrho = 3.10$ g/cm³
d) $NaCa_2Mg_5(Si_7Al\ O_{22})(OH)_2$; $\varrho = 3.07$ g/cm³

In the present work we have measured the total attenuation coefficients for different gamma-ray energies in five samples obtained from diamond drill holes. We have discussed the results and compared them with theoretically calculated values. The agreement is good, as is shown by Figs. 2—6, which seems to suggest that theoretically evaluated attenuation values can be used if the chemical composition of the sample is known.

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