Fermilab Library
0 1160 0018637 3

A paper submitted for the Poster Session
in "Int'l Sympo. on Neutrino-Astrophys."
at Takayama, Japan, 1992 Oct.19-22

Study of Superheated Superconducting Granule Detector: Responses of a 30micron-diam tin granule to 60keV photons at temperature of 30mK

TAKEO EBISU AND TADASHI WATANABE*

Department of Physics, Kobe Univ., Kobe 657, Japan
*) Department of Information Systems,
Tokyo University of Information Sciences, Chiba 265, Japan

Abstract. We report preliminarily some results of recent experiments in which 60keV photons were irradiated to a single tin sphere of diameter 30μm in applied fields less than the critical field H_{sh} at temperature 30mK in a dilution refrigerator.

Counting rates were obtained for the specimen having flipped in an hour at each ten points in field strength. We demonstrate that the spectrum of absorbed energies can be derived with superconducting granules by changing the strength of the applied field. Taking into account the original intensity of gamma-ray sources used, the photon mass attenuation length in intervening absorbers, and K- and L-edge absorption energies of tin, we conclude that the superconducting granule of diameter 30μm reacts to excited electrons with energies less than 10keV.

Previously we have confirmed the response energy down to 1 MeV for superheated superconducting tin granules of diameter 100$\sim$200μm at 2$\sim$3K by irradiating alpha-rays. Therefore, the improvement in response energy was attained by two orders of magnitude with a 30micron-diam granule at temperature of 30mK.

1. Introduction. Cryogenic methods are now well-known to be very useful for catching small signals caused by solar neutrinos and/or weakly interacting massive particles. In a series of experiments we have investigated some properties of superconducting spherical tin micrograins to be used as a device in the cryogenic particle detectors.

This is a preliminary report on responses of a single tin sphere of diameter 30μm which was irradiated with 60keV photons in applied fields less than the critical field H_{sh} at temperature 30mK in a ^{3}He-^{4}He dilution refrigerator.

We obtained counting rates of the specimen flipping in an hour at each ten points in field strength. Minimal energy deposits are estimated at each field strength from temperature increases required for the phase transition on the bases of the specific heat in the superconducting state and a working hypothesis of the global heating. Then we present that the spectrum of absorbed energies is derived by making a differential counting rate with respect to the deposited energy. The spectrum has two peaks at $\sim$30keV and $\sim$55keV: the former due to excited electrons from the K shell by primary γ-rays of 60keV and the latter due to ones from the L shell of tin. The ratio of counting rates about the two peaks is read as 4 to 1 in accordance with the mass absorption coefficient of the K shell to that of the L shell at photon energy of 60keV.

Taking account of the original intensity of gamma-ray sources used, the photon mass attenuation length in intervening absorbers, and K- and L-edge absorption energies of tin (the specimen) and copper (neighboring signal coils), we conclude that the superconducting specimen of diameter 30μm reacts to excited electrons with energies less than 10keV by γ-rays.

Previously we examined that superheated superconducting tin granules of diameter 100$\sim$200μm reacted to energy deposit down to 1 MeV at 2$\sim$ 3K with α-rays from ^{241}Am.[1] Therefore we have lowered the response energy by two orders of magnitude with a 30μmϕ specimen at 30mK.

2. Experimentals. A single tin granule of diameter 30μm and a 20-turn detection coil of copper wire of diameter 60μm are glued together with varnish (*GE7031*) and are completely immersed in liquid helium in a small container made of epoxy resin (*Stycast 1266*) which is connected with a ^{3}He-^{4}He mixing chamber (Fig.1). The container is wound with a superconducting coil of Nb-Ti-Cu wire of diameter 117μm in four layers, on which three gamma-ray sources of ^{241}Am(0.5μCi$\pm$10% each) are attached in equiangle with each other on a level with the tin granule set inside. The superconducting magnet produces field up to 600G with

error less than 0.1G.

The cooling rate of the refrigerator employed is about 70μW at 100mK and the temperature in the mixing chamber is monitored with a carbon thermometer inserted in it. Temperature lower than 20mK can be stably kept in a continuous operation mode of the refrigerator, though much lower one than 15mK is attainable in a single operation mode.

3. Data acquisition and results. Using a sphere of diameter 30μm singled out from the tin powder offered by G.Waysand, first we have measured the superheating superconducting critical field $H_{sh}(T)$ at temperatures ranging from 30mK to 3.0K with no irradiations. Almost all the data obtained several times at each temperature are well traced with the conventional curve of $H_{sh}(T) = H_{sh0}[1-(T/T_c)^2]$, T_c=3.72K. The maximum strength of field $H_{sh0} = H_{sh}(30\text{mK})$ is 327.5G as a mean value, while by 0.6% (about 2.0G) less field was obtained under irradiations. We shall use the conventional formula shown above with $H_{sh0} = 325.6$G for analyzing the results in irradiation experiments.

Each signal induced in the detection coil was received in a digital storage scope via wide-band amplifiers. Figure 2 shows one of line shapes for the signals recorded when an applied field is increased beyond H_{sh}.

Next, responses of the specimen to 60keV photons were studied at temperature of 30mK at ten points in field strength less than the critical field H_{sh}(30mK). We counted the number of the specimen having flipped in an hour. When any signal was not observed in six minutes, we reset the field and continued the observation for the next period of six minutes. Before resetting the applied field, we increased the field once up to the critical value of 325$\sim$326G to assure the specimen making a phase transition. Such observation has been performed at ten field-strengths. The numbers obtained for flips in an hour are shown in Table 1 and in Fig.3.

4. Discussions and conclusions. The radioactive isotope ^{241}Am used in this experiment radiates both alpha-rays (5.5MeV) and gamma-rays (11.9keV, 0.78%; 13.9keV, 13.2%; 17.8keV, 18.1%; 20.8keV, 4.9%; 26.3keV, 2.5%; 59.5keV, 35.3%). By taking account of the original intensity of each source (0.5μCi) and absorption of the radiations by intervening materials, we see that only 59.5keV γ-rays can reach the specimen (Table 2) except for secondary X-rays. While the initial intensity of 23photons/min is estimated for the six energy-spectra of gamma rays, only 0.54photons/min are expected for the 59.5keV rays to be absorbed while traversal along the diameter of the specimen.

At each applied field H_a, $\Delta H = H_a - H_{sh}$ represents deficit for the specimen to flip owing to the field alone. Beyond a threshold field H_{a0},

the counting rate of flips increases with field strength and reaches a maximal as is expected. The threshold field H_{a0} turns out to be around 315G for 60keV photons. A temperature rise of about 640mK is required for the phase transition at the field strength. By using the specific heat in the superconducting state and the global-heating picture, we can convert the temperature rise of 640mK into deposited energy of 65keV which coincides roughly with the photon energy.

We expect 32 photons or less of primary gamma-rays of 60keV to be absorbed in an hour by the specimen, whereas the counting rate appears to reach a maximal of 25flips/hour.

In Fig.4a we traced out a curve standing for counting rates to calculated energy-deposit, which is considered to be cumulatively contributed from excited electrons with various energies. Figure 4b shows differential counting rates with respect to energy deposit, which has two peaks; One is at 60 keV or less and the other is at ~30keV. The former should be due to excited electrons from the L shell by primary γ-rays of 60keV and the latter due to ones from the K shell of tin. The ratio of counting rates about two peaks is read as 4 to 1 in accordance with the mass absorption coefficient of the K shell to that of the L shell at photon energy of 60keV.

Discussions given above are preliminary and necessitate more elaborate consideration including K- and L-edge absorption energies and secondary X-ray energies not only for tin but also for materials adjacent to the specimen, as well as contribution from kicked electrons through the Compton scattering.

We conclude that the superconducting granule of diameter 30μm reacts to electrons with energies less than 10keV which are excited by gamma-rays. Previously we have confirmed the energy sensitivity down to 1 MeV for superconducting tin granules of diameter 100~200μm at 2~ 3K by irradiating alpha-rays.[1] Therefore the improvement in response energy with the tin granule was attained by two orders of magnitude by decreasing temperature from 2~ 3K down to 30mK and by downsizing the granule by a factor of 3~7.

We thank Prof.G.Waysand for offering us tin micrograins used as specimens in this experiment. This work is supported in part by Grant-in-Aids for Scientific Research from the Ministry of Education, Science and Culture, #02211210 and #04452028.

Reference

1) T.Ebisu, N.Nakagawa and T.Watanabe, Jour.Phys.Soc., Jpn **60** #4 (1991) 1413.

Table 1

H_a is the applied field in gauss. H_a–H_{sh} stands for deficit for the specimen to flip owing to each applied field alone. N is the counting rate(1/hour) of flipping. ΔE shows energy estimated for the specimen to make a phase transition due to temperature rise in each applied field.

	H_a(G)	$H_a - H_{sh}$	N	ΔE(keV)
(0)	325.60(=H_{sh})			
(1)	324.37	−1.23	24	0.9
(2)	323.26	−2.34	25	3.2
(3)	322.39	−3.21	23	6.2
(4)	321.31	−4.29	25	11
(5)	320.39	−5.21	26	16
(6)	319.20	−6.40	22	24
(7)	318.28	−7.32	12	31
(8)	317.24	−8.36	7	42
(9)	316.37	−9.23	5	51
(10)	315.22	−10.38	0	65

Table 2

Taking account of the original intensity of ^{241}Am (0.5μCi) and the geometrical configuration of our irradiation apparatus, the initial intensity (I_0) of gamma rays is estimated to be 23 photons/min. Gamma-rays consist of six energy-lines E[keV] with relative intensity in % noted. I_1[1/min] is the intensity of them remaining after traversal through a solenoid coil(Nb-Ti-Cu) for the superconducting magnet, a cylindrical container (epoxy resin) and a detection coil(Cu) therein. I_2[1/min] is the intensity after traversal through the tin specimen of diameter 30μm and $I = I_1$–I_2 represents expectation numbers of photons absorbed in the specimen.

	(1)	(2)	(3)	(4)	(5)	(6)
E[keV]	11.89	13.9	17.8	20.8	26.35	59.54
%	0.78	13.2	18.1	4.87	2.47	35.3
I_1[1/min]	2.7E-21	1.0E-10	2.2E-9	9.8E-7	3.0E-4	4.23
I_2[1/min]	5.3E-22	3.8E-11	1.3E-9	7.0E-7	2.5E-4	3.69
$I = I_1$–I_2	2.2E-21	6.2E-11	0.9E-9	2.8E-7	0.5E-4	0.54

Fig.1

The specimen-container made of epoxy resin (*Emerson and Cummings Stycast 1266*) is connected through a stainless-steel pipe with the bottom of the mixing chamber. A tin granule and a detection coil glued together with varnish are completely immersed in *Liq.*He in the container on measurement. The coil is connected with amplifiers. The container is wound with a superconducting coil in four layers, on which three γ-ray sources of ^{241}Am are attached (though only one is depicted) in equiangle with each other on a level with the specimen set inside.

Fig.2

A typical line shape that has a *FWHM* of 70~80ns at 326G and 28mK. The amplitude is given in 20mV/div for ordinate after amplified and in 50ns/div for abscissa.

Fig.3

Responses of a granule of diameter 30μm to 60keV photons at ten points in field strength applied at 30mK. The counting rates are shown for flips in an hour. The smallest energy deposit ΔE required for the granule to flip can be estimated by taking account of the specific heat in the superconducting state and a global-heating hypothesis. A curve of broken line stands for the superheating superconducting field $H_{sh}(T)$ in no irradiations.

Fig.4a

A curve tracing out the counting rates to ten points in energy.

Fig.4b

A curve representing the differential counting rate with respect to energy deposit showing two peaks which should be due to excited electrons from the L shell by primary gamma-rays of 60keV and due to ones from the K shell of tin.

Takeo Ebisu: Department of Physics, Kobe University, Kobe 657, Japan
Tadashi Watanabe: Department of Information Systems, Tokyo University of Information Sciences, Chiba 265, Japan

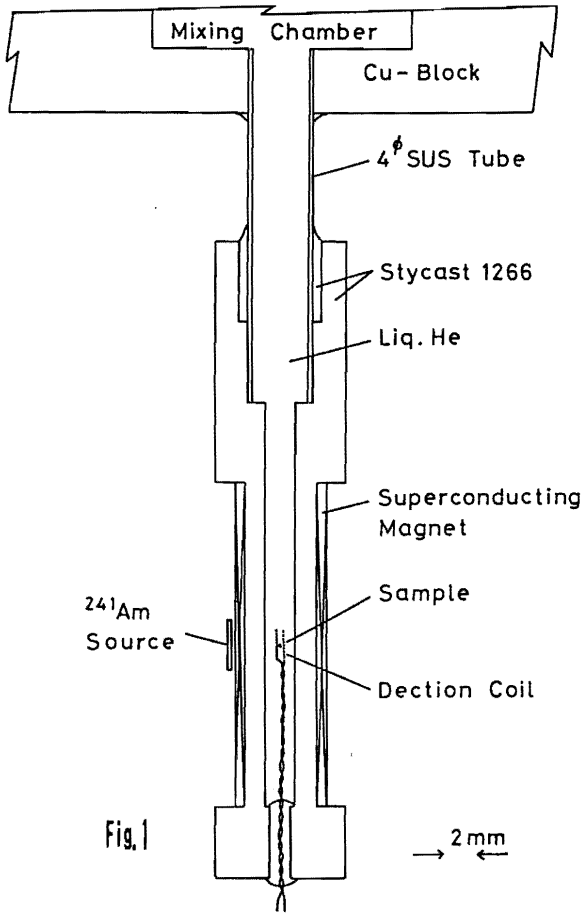
Mixing Chamber
Cu-Block
4φ SUS Tube
Stycast 1266
Liq. He
Superconducting Magnet
Sample
241Am Source
Dection Coil
2 mm

Fig. 1

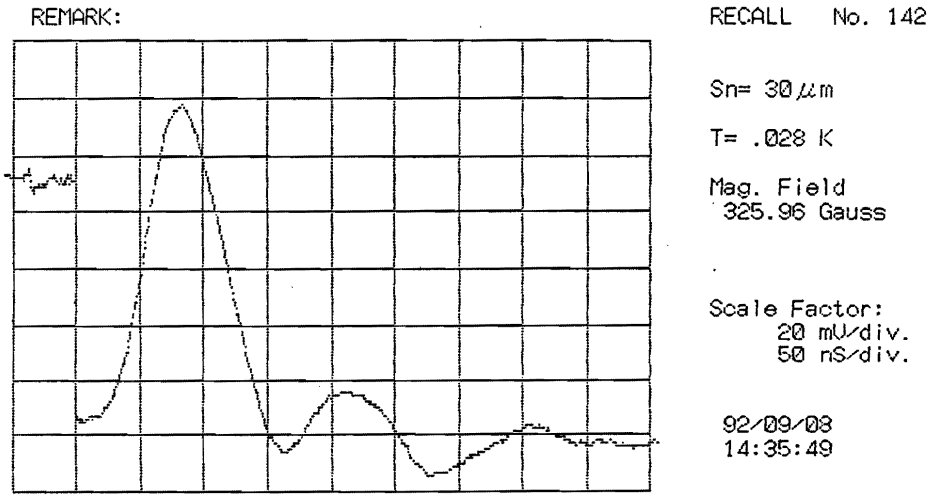
REMARK:
RECALL No. 142
Sn= 30μm
T= .028 K
Mag. Field
325.96 Gauss
Scale Factor:
20 mV/div.
50 nS/div.
92/09/08
14:35:49

Fig. 2

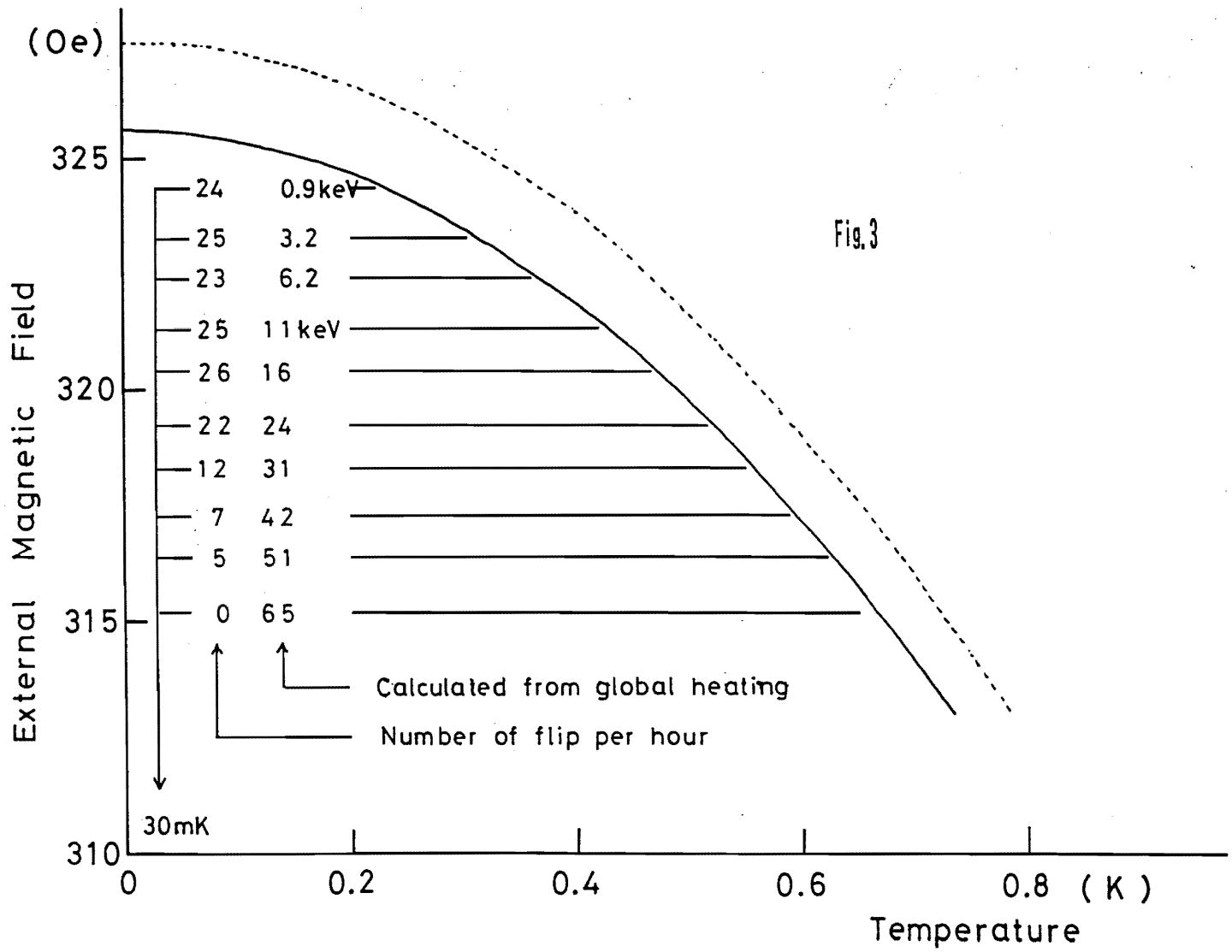
(Oe)
325
320
315
310
External Magnetic Field
24 0.9keV
25 3.2
23 6.2
25 11keV
26 16
22 24
12 31
7 42
5 51
0 65
Calculated from global heating
Number of flip per hour
30mK
0
0.2
0.4
0.6
0.8 (K)
Temperature

Fig. 3

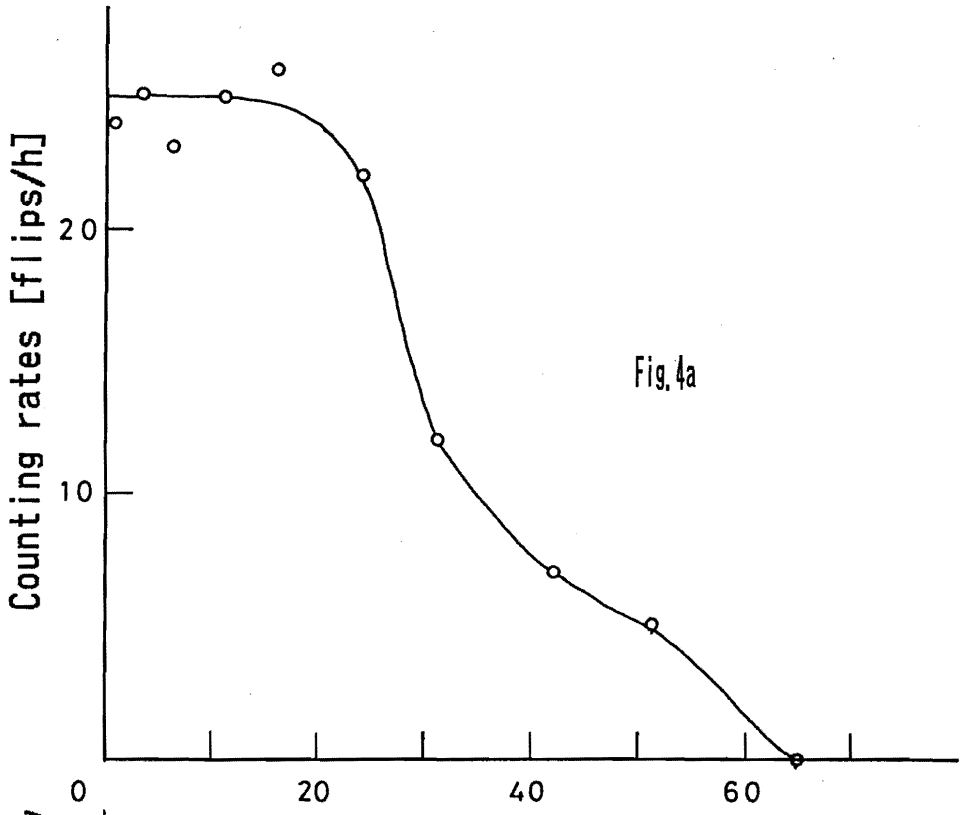
Counting rates [flips/h]
20
10
0
20
40
60
energy [keV]

Fig. 4a

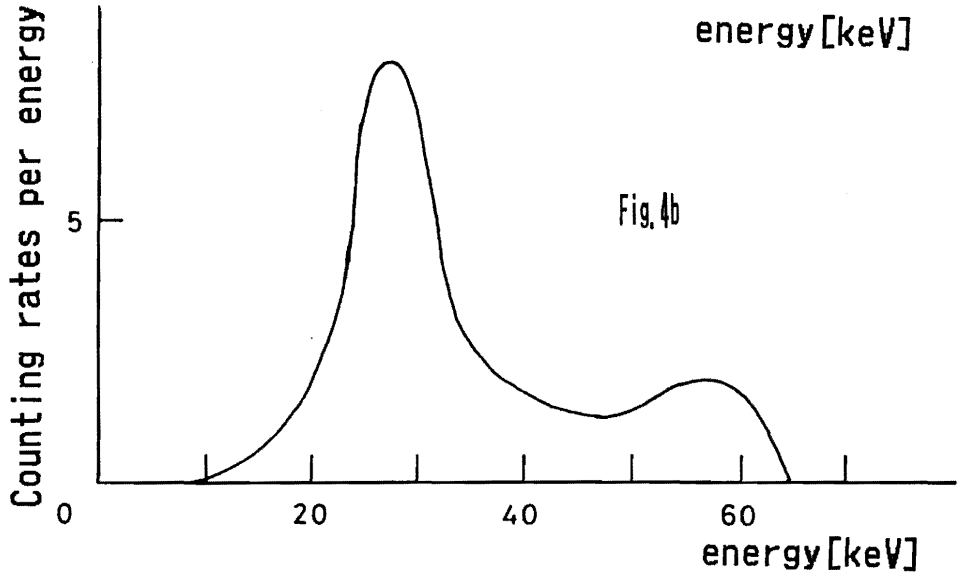
Counting rates per energy
5
0
20
40
60
energy [keV]

Fig. 4b