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CRYSTAL SPECTROMETER MEASUREMENT OF ÇEKMECE TR-1 THERMAL NEUTRON SPECTRUM

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Ö. Akyüz, F. Bayvas, Ç. Cansoy, F. Domaniç

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SUMMARY

The Thermal Neutron Spectrum of Cekmece TR-1 was measured by using a double drystal spectrometer and $NaC\ell$ crystal with its (200) plane as monochromator. The neutron energy which corresponds to the maximum of thermal flux distribution was found to be $E_o = 0,0595$ ev.

Assuming that the flux distribution to be Maxwellian an attempt was made to analyze the measured data to evaluate the effective neutron temperature in the beam hole. Because the theoretical expressions given in the latest publications are found to be unsatisfactory in representing neutron reflectivity for slow neutrons, an experiment was carried out to determine the reflectivity in dependence of neutron energy, the results of the experiment showed that the reflectivity is proportional to $E^{-0,45}$. By using this empirical relation the effective neutron temperature was found to be $\approx 337°K$.

1. *INTRODUCTION*

The experimental determination of thermal and epithermal flux distribution in a beam hole of any research reactor is required for many purposes. The temperature of neutrons in the core is of importance to reactor design and to the study of the mechanism of moderation while the beam neutron temperature is of great value to the scientist using the neutron beam for research.

It is because of these reasons that the flux distribution of thermal neutrons have been measured with most research reactors.[1, 2,3,4]

When a double crystal spectrometer was installed at TR-1, we thought an experimental determination of thermal flux distribution to be essential to the proper use of the beam hole neutrons.

We were mainly interested first in finding out the actual relative energy distribution to carry out diffraction measurement and secondly in measuring the neutron temperature for effective cross section evaluations.

We also hoped that our experimental data may constitute the thermal components of the reactor spectra, because the measurements in resonance and fast region of the spectra are being carried out by other methods.

2. *MEASUREMENTS*

The relative flux distribution in the thermal energy region has been measured using a double crystal spectrometer which was designed to perform neutron diffraction measurements. The other end of the beam hole in front of which the spectrometer was installed, was very close to the core so that the distance between the fuel elements and the beam hole end was approximately 5 mm. The arrangement of fuel elements containing 90% enriched fuel is shown in (Fig. 1).

The beam was brought onto the crystal by a collimator of circular cross-section and with an angular divergence of 42 minutes of arc. The detector used was a (24" in length and 2" in diameter) BF_3 tube using enriched gas at 40,6 cm. pressure. Measurements were made using (200) planes of $NaC\ell$ crystals. The counting rates versus energy which are proportional to relative flux are shown in (Fig. 2). It is seen from this graph that the neutron energy corresponding to the maximum of the distribution is $E_{max} = 0.0595$ ev.

3. RESULTS AND ANALYSIS OF DATA

In order to analyze the data in terms of effective neutron temperature we felt that they had to be corrected for the following energy dependent effects: Contamination of the beam by second order crystal reflections; crystal reflectivity; instrumental resolution and counter efficiency.

Since the second order effect for (200) plane of NaCℓ crystal which was used for the measurement was already determined, we first corrected the data for this effect. (Fig. 3) represents the corrected data.

Instead of correcting the data for other effects as well, which would require a rather time consuming work, if it is carried out with a desk calculator, we preferred to find out the neutron temperature as follows:

The observed counting rate versus energy is certainly a product:

$$C(E) = \varepsilon R(d\Phi) \qquad (1)$$

where C(E) is for the second order effect corrected energy dependent counting rate, ε is the BF_3 counter efficiency, R is the crystal reflectivity, $d\Phi$ is the differential flux which includes also the resolution width ΔE of the spectrometer.

Since it is assumed that the thermal flux is Maxwellian, we may write:

$$d\Phi = AEe^{-E/kT}\,dE \qquad (2)$$

where A is a constant.

On the other hand because the differential (dE) should be identical with the resolution width of the instrument the later can be written as:

$$dE \approx \Delta E = \text{const x } E^{3/2} \qquad (3)$$

If we replace now (dE) in equation (2) by the equation (3) we get:

$$d\Phi = BE^{5/2}\ e^{-E/kT} \qquad (4)$$

The counter efficiency can be calculated at any energy from the following equation:[5]

$$\varepsilon = 1 - e^{-N\ x\ CE^{-1}} \qquad (5)$$

where N is the number of atoms per cm^3 in the counter, x is the length of the counter, C is a numerical constant giving the 1/v slope of the $B^{10}(n,\alpha)Li^7$ cross section and E is the energy.

The calculated value for the BF_3 proportional counter used in our measurements for thermal neutron energies is very close to unity so that one is allowed to neglect the influence of the counter efficiency on the flux distribution.

The neutron temperature calculated from the spectrometer counting rate seems to be very sensitive to the crystal reflectivity: If one takes, for example, $R = \text{const. } E^{-1/2}$, which might be a good guess for NaCℓ (200) the flux distribution can be represented by the equation

$$C(E) = B'E^2 e^{-E/kT} \qquad (6)$$

and by differentiating this equation we can get for the energy corresponding to the maximum of the distribution.

$$E_{max} = 2kT$$

If we assume on the other hand that the crystal reflectivity is constant for the energies concerned then a different equation for E_{max} may be obtained:

$$E_{max} = 5/2\ kT$$

It was necessary therefore that much care should be given to the representation of crystal reflectivity in dependence of energy.

For this purpose we tried first to use the theoretical expression for the reflectivity given in the latest publications.

It was seen from these expressions that the reflectivity for slow neutrons to be proportional to θ^2(θ being Bragg angle) in the small angle region ($<10°$) where the actual measurement of flux distribution was carried out. This means that the reflectivity is expected to be proportional to $1/E$. If one now inserts this, together with equation (4) into equation (1) the energy dependent counting rate will be represented as follows:

$$C(E) = B''E^{3/2}\ e^{-E/kT} \tag{7}$$

From this we find by derivation an expression for the energy corresponding to the maximum of the flux distribution.

$$E_{max} = \frac{3}{2}\ kT \tag{8}$$

Since the measured energy E_{max} = 0,0595 ev., one can get from equation (8) the neutron temperature, $T = 460°k$. Compared with the actual pool water temperature $\approx 293°k$, the measured value seemed to us too high.

One can estimate the effective neutron temperature from the measured water temperature by using the relation given by Coveyou et al[8] which is shown below:

$$\frac{T_n}{T_m} = 1 + 0,46\Delta \qquad (9)$$

where T_n is the effective neutron temperature, T_m is the actual moderator temperature and Δ, being a proper value to the reactor used, can be calculated as follows:

$$\Delta = \frac{4\Sigma_a(kT)}{\xi\Sigma_s}$$

We calculate that this equation gives a numerical value of (0.14033) for TR-1 Reactor.

By inserting this value into equation (9) and taking into account T_m = 297°k, we obtain T_n = 316°k.

We can conclude from this result, that the expected effective neutron temperature must be in the neighborhood of (316°K).

It was therefore obvious that the theoretical expressions for slow neutron reflectivity are not satisfactory. Those relations were derived mainly by assuming a similarity between X-ray and neutron diffraction. Apparently, there is still much work required, both theoretical and experimental, to set up exact relations for neutron reflectivity of crystals. We decided therefore, to determine experimentally the reflectivity of (200) plane of NaCℓ crystal to interpret our flux distribution measurements.

For this purpose the crystal was put on the second crystal table of the double crystal spectrometer and its reflectivity in dependence of energy was determined by measuring the incident and reflected beam intensity and by taking their ratio according to the equation:

$$R = \frac{I}{I_o} \qquad (10)$$

The values of R were plotted then on double logarithmic paper as shown in (Fig. 4), which gives a straight line as expected.

We may certainly accept that the reflectivity of a crystal can be expressed as follows:

$$R = (\text{Constant} \times E^{a}) \tag{11}$$

The indices (a) can now be determined from the slope of the straight line. According to (Fig. 3) $a = -0{,}45$ which means that

$$R = \text{Constant} \times E^{-0{,}45} \tag{12}$$

By using this expression for reflectivity the effective neutron temperature was found to be T = 337°K which is reasonable.

It should be pointed out that the reflectivity measurements require still some improvements. Experiments to establish empirical expressions and to compare them with existing theories are being planned. Until then our interpretation of TR-1 thermal neutron spectrum can be considered approximate.

ACKNOWLEDGMENT

We like to express our thanks to Dr. Vance Sailor from Brookhaven National Laboratory for valuable discussions.

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FIGURE CAPTIONS

Fig. 1 : The Arrangement of the Core Configuration and the Beamholes.

Fig. 2 : The Measured Counting Rates Versus Energy.

Fig. 3 : The Corrected Counting Rates Versus Energy, Corrected for Second Order.

Fig. 4 : The Measured Reflectivity of $NaC\ell$ Crystal (100) Plane.

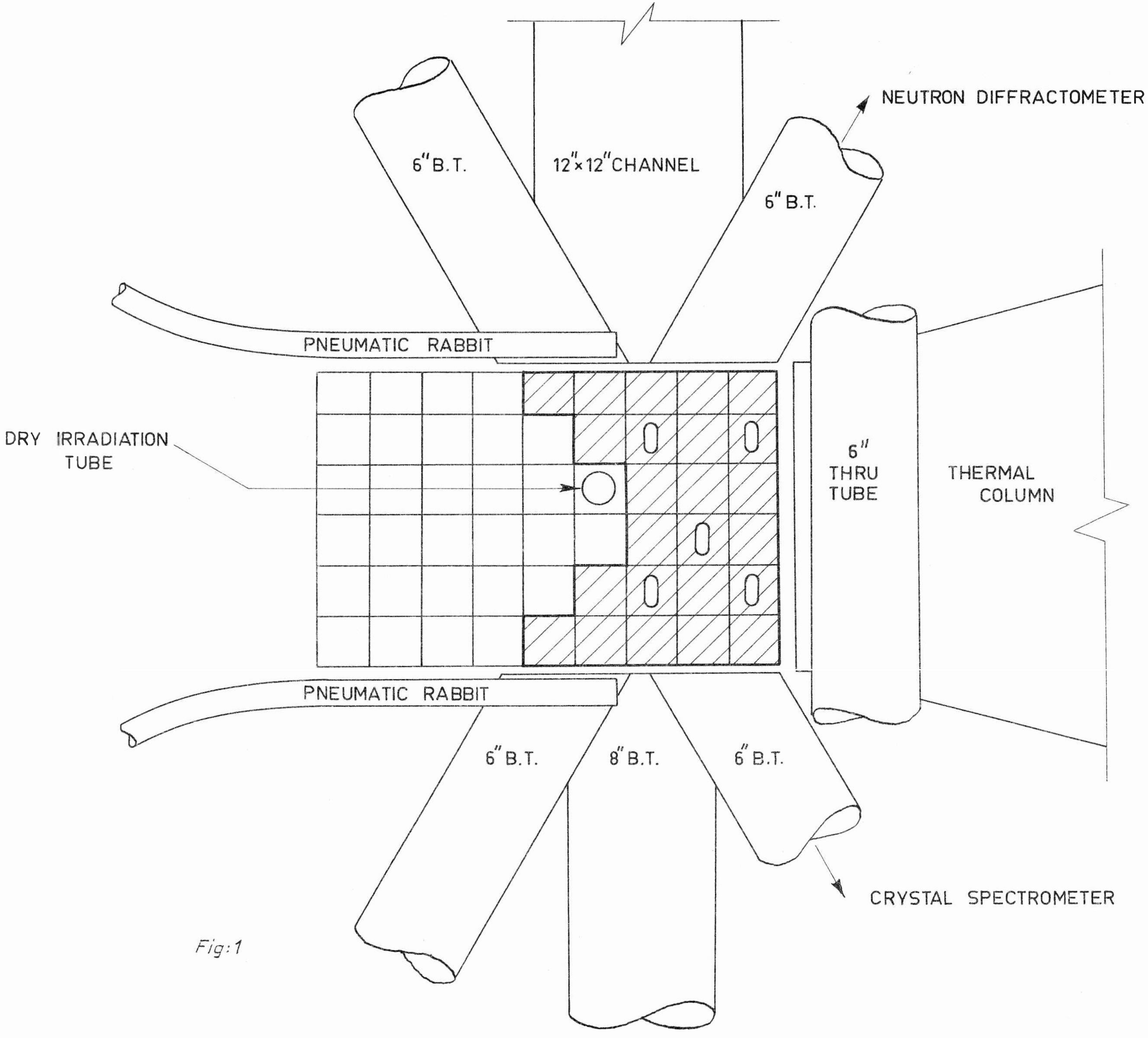
NEUTRON DIFFRACTOMETER
6" B.T.
12"×12" CHANNEL
6" B.T.
PNEUMATIC RABBIT
DRY IRRADIATION TUBE
6" THRU TUBE
THERMAL COLUMN
PNEUMATIC RABBIT
6" B.T.
8" B.T.
6" B.T.
CRYSTAL SPECTROMETER

Fig:1

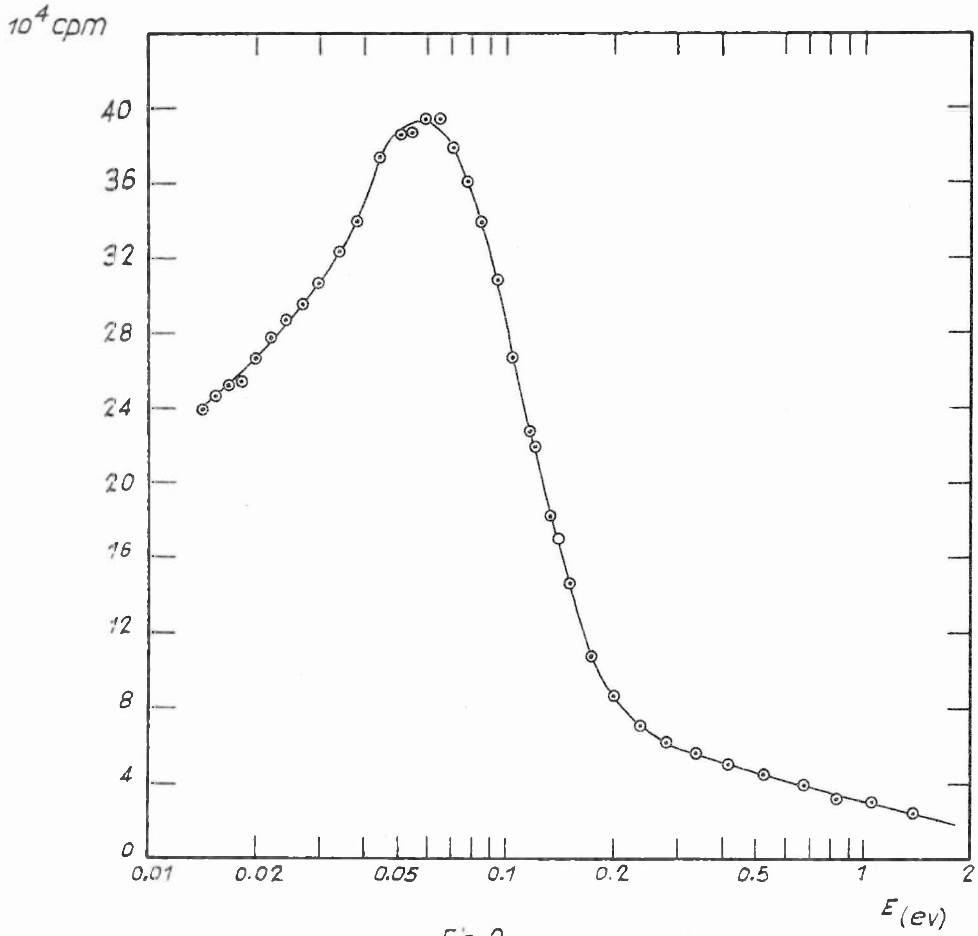
10^4 cpm
40
36
32
28
24
20
16
12
8
4
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
E (ev)

Fig:2

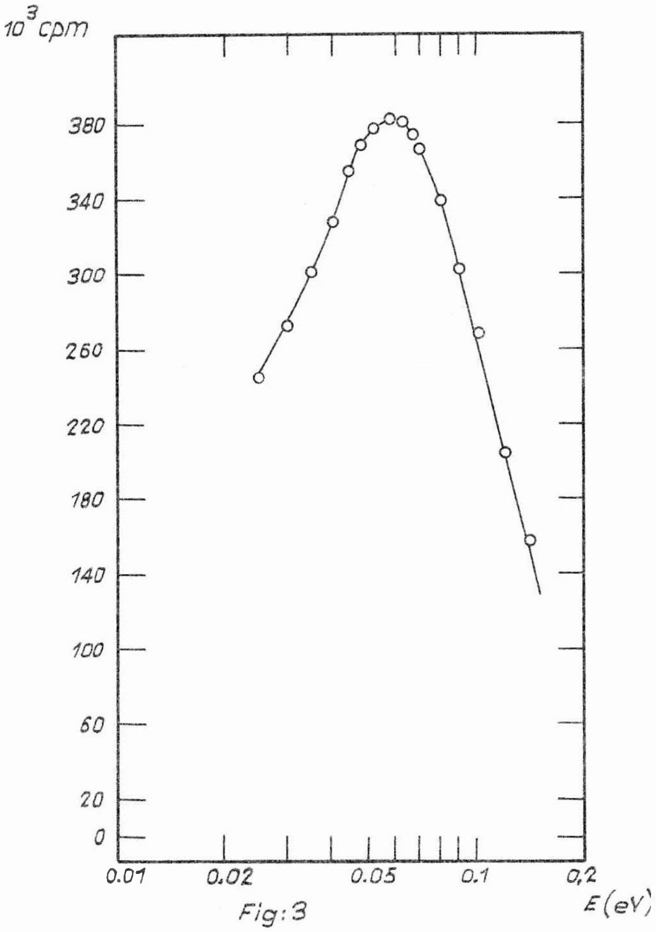
10^3 cpm
380
340
300
260
220
180
140
100
60
20
0
0.01
0.02
0.05
0.1
0,2
E (eV)

Fig:3

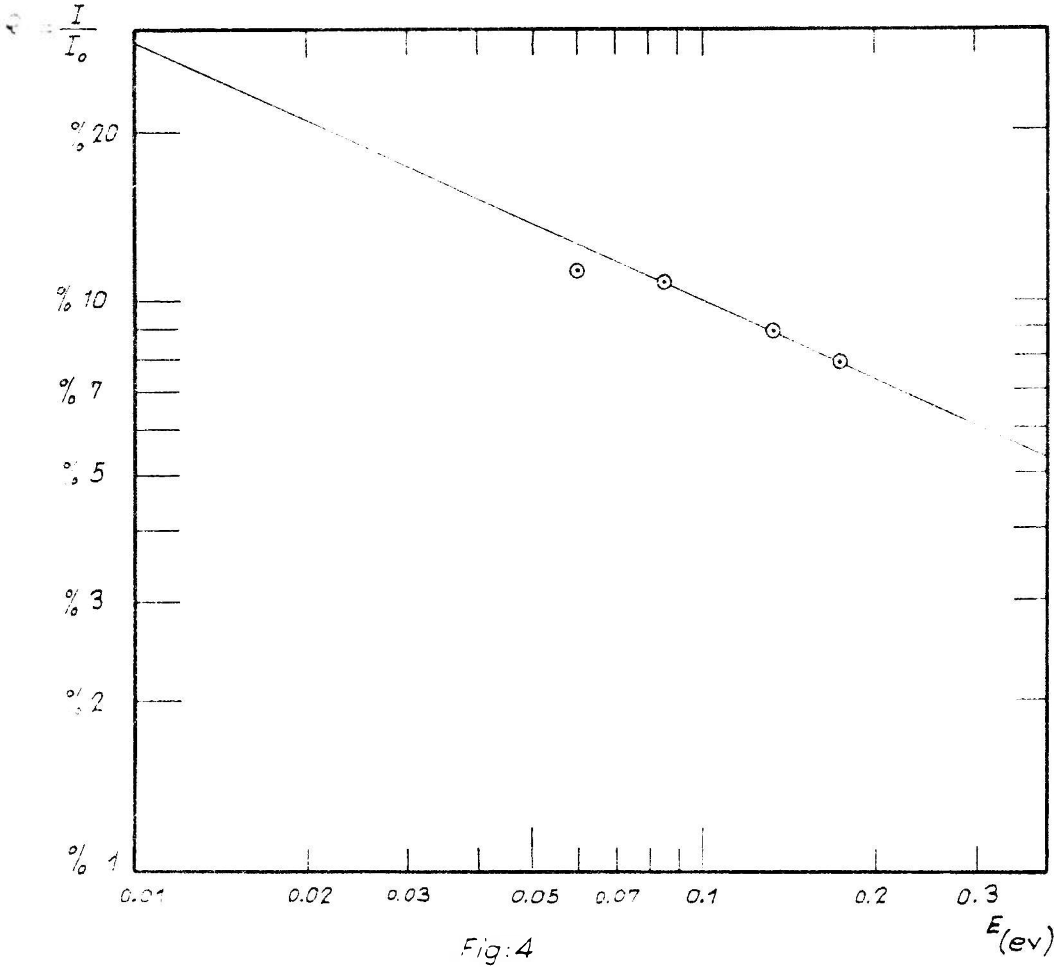

Fig: 4