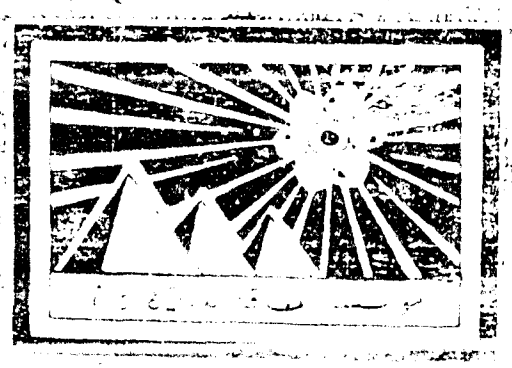

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THERMAL NEUTRON CAPTURE GAMMA-RAYS IN IRON

By

A.M. HASSAN, H.M. ABU-ZEID
AND I. HAMOUDA

1970

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C O N T E N T S

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By

A.M. Hassan, H.M. Abu-Zeid

and I. Hamouda

A B S T R A C T

Thermal neutron capture gamma-radiation from natural iron sample was investigated with the aid of the three-crystal scintillation pair spectrometer in an external beam of thermal neutron from UA-RR-1.

Previously unreported lines in natural iron of energies 6.95, 6.75, 5.35 and 5.18 MeV have been observed.

1. INTRODUCTION

Earlier studies of the iron neutron capture gamma-ray spectra were made by Hammermesh and Hummel [1] and by Kinsey and Bartholomew [2]. Various techniques of gamma-ray spectroscopy have been employed [3-8]. Other studies from thermal neutron radiative capture has been done [9-13] by using the recently developed Ge(Li) detector. On the other hand, Wasson and Drapper [14] and Block [15] have measured (n, γ) spectra which result from resonance neutron capture in iron.

Moreover, the energy levels in Fe^{57} have been established from studies of the inelastic scattering of protons in iron as well as the $Fe^{56}(d,p)Fe^{57}$ reaction [16]. Vervier and Bartholomew [17,18] have made angular correlation measurements on the iron neutron capture gamma-ray cascade and determined the spin of the 0.3662 MeV level to be 3/2. The same workers investigating the circular polarization of the 7.639 MeV gamma-ray have established that this line is actually a doublet with 0.49 ± 0.19 of the intensity representing a ground-state transition and the remainder a transition to the 14 MeV first excited state.

The energies of the first and second excited states have been determined by Bellicard and Moussa [19].

The 0.136 and the 0.366 MeV levels have been excited and their decay properties established in Coulomb excitation studies [20]. From the spectrum following Co^{57} decay, it has been determined [6,21,22] the energies and branching ratios of the second, third and fourth-excited states. The gamma-ray spectrum following the decay of Mn^{57} indicates decays to the 0.136, 0.366 and 0.707 MeV levels [23].

The properties of the ground state, and the energy levels in Fe^{57} have been reported [24,25].

2. EXPERIMENTAL PROCEDURE

The essential feature of the present experiment have been described in reference [26], certain aspects of the performance of the apparatus, however, which are characteristic of the experiment, affect the nature of the results obtained and their interpretation. These will be treated briefly here.

The capture gamma-rays produced in a target placed in an external collimated beam of thermal neutrons from the U.A.R. 2 MW research reactor are detected by a three crystal NaI(Tl) pair spectrometer. The center crystal (1.75"ϕx2"L) of the spectrometer has a resolution 7.5% for the Cs^{137} line of 0.662 MeV, while the side crystals (each 3"ϕx3"L) have resolution 10% and 9.5% for Cs^{137} line of 0.662 MeV.

The employment of the pair spectrometer in the measurements of high energy gamma-rays has the evident advantage that only one peak is present in the spectrum for each monoenergetic gamma-rays. In contrast if a single crystal were used for this purpose, the photo peaks of successive gamma-ray; would be super imposed upon the single and double escape peaks and the Compton distribution of higher energy gamma-rays.

In the pair spectrometer spectrum the strong capture gamma-rays of lead (7.38) MeV and aluminium (7.72) MeV appear as very weak background peaks arising from the capture of scattered neutrons in the apparatus. In addition the pair spectrum peaks are superimposed on a smooth rising continuum composed of the low-energy tails of the pair spectrometer peaks [27], which extend as weak, continuous background to rather low energies. The tail arises mainly from the escape of Bremsstrahlung and electrons from the center crystal of the pair spectrometer. Also gamma-rays may suffer small losses of energy through small-angle Compton scattering [28], before being detected. This latter effect has very slight influence on the pair peak efficiency and form.

In order to obtain the relative gamma-ray intensity the method is described in reference [29]. In (Table 1) I_γ is expressed in Photons/

100 neutron captures by normalizing the sum of the measured relative intensities to the sum of the absolute intensities determined by Adyasivich et al. [3] and Groshev et al. [5] for the same energy interval.

The absolute intensities calibration of this experiment was limited to 15% accuracy, however, γ -ray energies were determined to within $\pm$20 keV by using the results of other experiments. The energies of the levels of Fe^{57} is quite well known from the investigations of the (d,p) and (n,γ) reaction [25].

Several of the strong lines in the spectrum of the present experiment have been identified with previous results [3]. Using this for calibration together with the measured linearity of the electronic system, it was found that the majority of the remaining lines have energies which correspond to other known levels, exceptions are discussed individual.

3. EXPERIMENTAL RESULTS

The investigated specimen contained 25.3 gm of natural iron (99.9% purity) in form of a slab (4.5x1.5x0.2 cm^3). The sample was fixed with its face making an angle $\sim$10° with the beam of neutrons. The arrangement of counters were as shown in (Fig. 1) with the iron sample center at a distance 4 cm from the upper face of the central crystal. The spectrum was measured over the energy range 2 to 11 MeV and is shown in (Fig. 2).

Table 1 shows the gamma-ray energies measured in the present experiment. It also shows for comparison the high energy gamma-rays result of other authors [2,3,5,32,33,34].

The intensities relative to that of the 9.30 MeV are also given in (Table 1). These intensities are calculated from peaks No. 1,4,5,22,26 and 33 of (Fig. 2) after being corrected for the γ -ray absorbers between the sample and the central crystal [29]. The sum of the 36 gamma

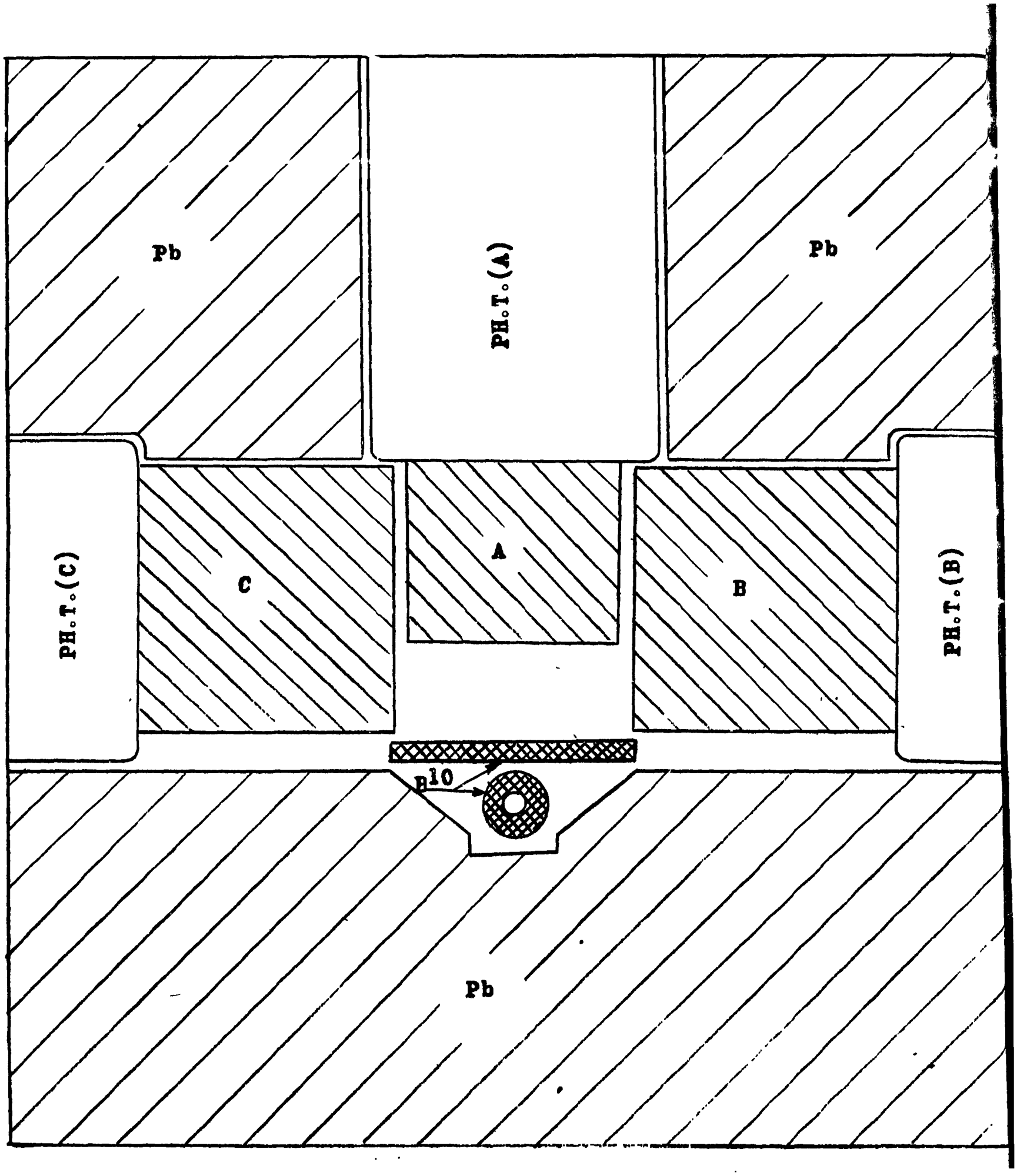

Fig. (1): Crystals Arrangement in Pair Crystal Spectrometer.

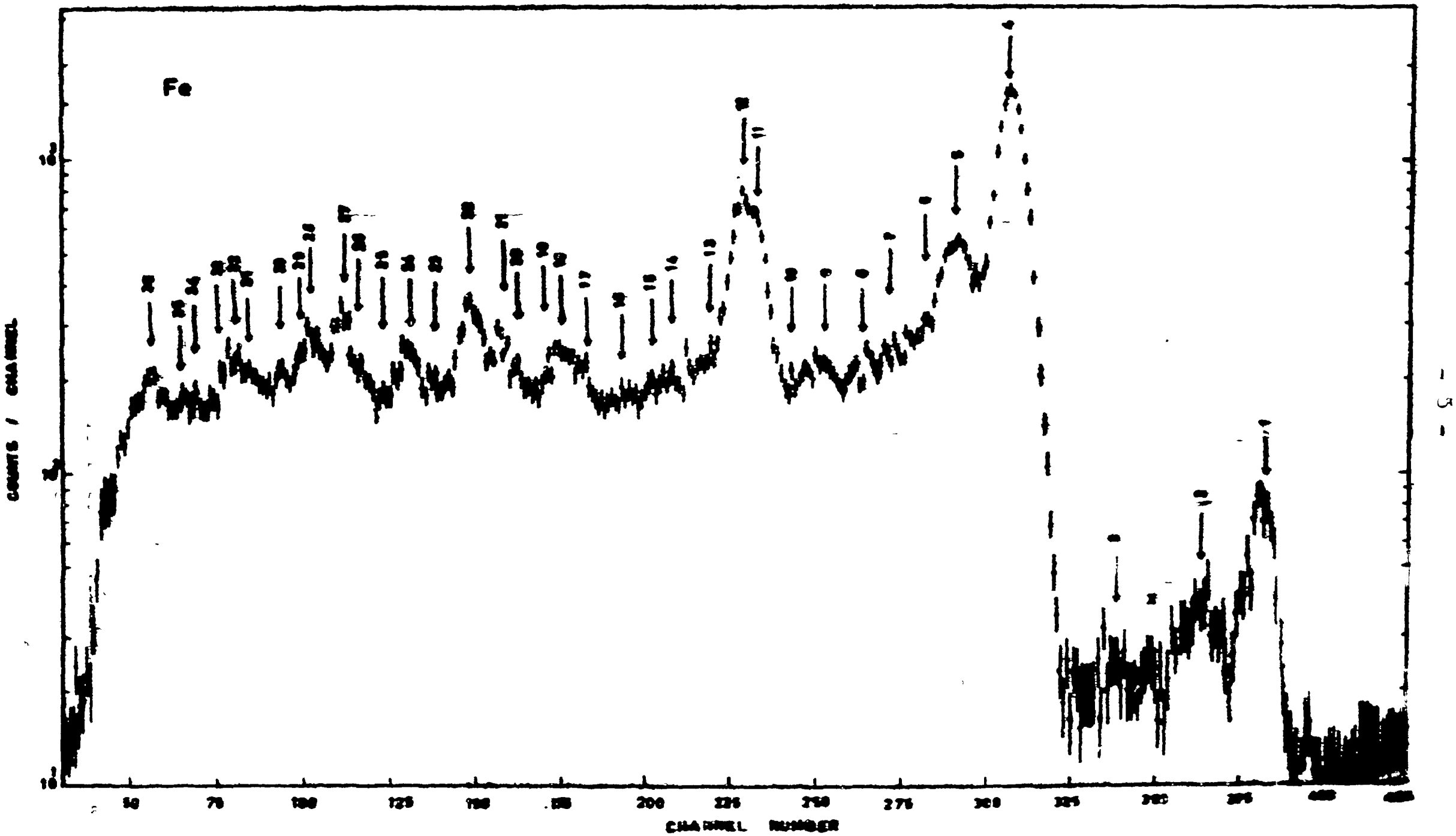

Fig. (2) PAIR SPECTROMETER SPECTRUM OF CAPTURE GAMMA RAYS FROM A NATURAL IRON SAMPLE (UNCORRECTED)

Line No.	Emmiung Isotope	Present Work			Kinsey et al.(2)		Adyasevich et al.(3)		Groshev et al.(5)		Loskutova et al.(33)		Ikagami et al.(32)		Murzin et al.(34)	
		Natural Iron			Natural Iron		Natural Iron		Natural Iron		Fe^{55}		Fe^{57}		Fe^{57}	
		E	R	I_γ	E.	I_γ	E.	I_γ	E.	I_γ	E.	I_γ	E.	R I_γ	E.	I_γ
—	Fe^{58}	——	——	——	1015 (4)	0.1	——	——	10 030(8)	0.03	——	——	——	——	14.8	2
1	Fe^{55}	●★9.30(2)	1.00	2.87	9.296(7)	2.7	● 9.295 (15)	2.70	9.298(5)	3.30	9.31	0.1	9.29	100	——	——
2	Fe^{59}	8.88(3)	0.11	0.31	8.872(10)	0.8	8.86 (6)	0.36	8.882(6)	0.50	8.88	1.2	8.87	16	——	——
3	Fe^{59}	8.34(3)	0.07	0.20	8.345(11)	0.8	8.34 (6)	0.36	8.350(8)	0.30	——	——	——	——	8.37	0.4
4	Fe^{57}	★7.63(2)	11.78	33.83	7.636(4)	26.0	● 7.636 (10)	21.6	7.643(4)	21.50	——	——	——	——	——	——
									7.626(4)	21.50	——	——	——	——	——	——
5	Fe^{55}, Fe^{57}, Fe^{58}	★● 7.28(2)	1.03	0.66	7.285(6)	3.5	● 7.276 (18)	5.2	7.277(6)	5.20	7.27 ●	3.0	7.29	2	7.28	7.2
6	Fe^{58}	● 0.95(2)	0.07	0.20	——	——	——	——	——	——	——	——	——	——	6.96	7.2
7	Fe^{54}	6.96(3)	0.04	0.10	——	——	——	——	6.921(8)	0.07	6.92	2.0	6.98	6	——	——
8	?	● 6.78(3)	0.04	0.10	——	——	——	——	——	——	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	6.504(8)	0.10	——	——	——	——	6.51	0.8
9	Fe^{57}	6.44(4)	0.21	0.61	6.389(6)	0.4	6.43 (3)	0.7	6.379(7)	0.60	——	——	——	——	——	——
10	Fe^{56}	6.27(3)	0.05	0.16	——	——	——	——	6.296(8)	0.10	6.27	3.0	——	——	——	——
									6.288(8)	0.10						
—	Fe^{55}, Fe^{58}	——	——	——	——	——	——	——	——	——	——	——	6.22	5	6.18	2.2
11	Fe^{57}	★6.04(2)	2.82	8.16	6.015 (7)	5.8	6.020 (15)	7.0	6.018 (5)	8.50	——	——	——	——	——	——
12	Fe^{57}	5.93(2)	2.80	8.26	5.914(10)	5.2	5.92 (3)	6.7	5.926(6)	6.30	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	——	——	——	——	——	——	5.87	2.6
—	?	——	——	——	——	——	——	——	5.787(8)	0.20	——	——	——	——	——	——
13	Fe^{56}	5.76(3)	0.09	0.26	——	——	——	——	5.788(8)	0.20	5.75	2.5	——	——	——	——
—	Fe^{54}	——	——	——	——	——	——	——	——	——	——	——	5.67	8	5.69	4.3
14	Fe^{55}, Fe^{58}	5.50(2)	0.15	0.43	——	——	5.51 (3)	0.6	5.499 (6)	0.20	5.50	2.0	5.46	5	5.50	0.8
15	Fe^{56}	● 5.35(2)	0.04	0.10	——	——	——	——	——	——	5.37	1.5	——	——	——	——
15	?	● 5.18(2)	0.04	0.10	——	——	——	——	——	——	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	5.048(8)	0.20	——	——	——	——	5.05	1.6
—	?	——	——	——	——	——	——	——	5.003(8)	0.20	——	——	——	——	——	——
17	Fe^{55}, C^{13}	4.98(2)	0.21	0.61	4.988(11)	0.5	4.94 (2)	0.8	4.958(5)	0.80	——	——	——	——	——	——
—	?	——	——	——	——	——	——	——	4.965(7)	0.10	——	——	——	——	——	——
18	Fe^{56}, Fe^{58}	4.81(2)	0.71	2.05	4.81 (2)	1.0	4.806 (10)	2.1	4.818(8)	1.80	——	——	——	——	——	——
—	Fe^{54}, Fe^{58}	——	——	——	——	——	——	——	——	——	4.73 ●	2.8	4.71	7	4.74	5.4
19	Fe^{58}	4.68(2)	0.11	0.31	——	——	——	——	4.688(7)	0.30	——	——	——	——	——	——
—	?	——	——	——	——	——	——	——	4.662(7)	0.10	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	——	——	——	——	——	——	4.56	2.2
20	Fe^{55}, Fe^{57}	4.48(2)	0.14	0.41	——	——	——	——	4.462(7)	0.50	4.48	1.8	4.50	9	——	——
21	Fe^{57}	4.48(2)	0.34	1.04	4.44 (2)	1.0	4.465 (16)	2.2	4.465(8)	1.40	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	——	——	——	——	——	——	4.35	2.8
—	Fe^{57}	——	——	——	——	——	——	——	4.276 (5)	0.60	——	——	——	——	——	——
22	Fe^{57}	★4.20(2)	1.50	4.30	4.21 (2)	2.8	4.220 (15)	4.3	4.217 (6)	2.30	——	——	——	——	——	——
—	Fe^{55}, Fe^{58}	——	——	——	——	——	——	——	——	——	4.17	1.5	——	——	4.18	2.3
23	Fe^{57}	4.08(2)	0.21	0.61	——	——	4.09 (2)	1.4	4.094 (6)	0.40	——	——	——	——	——	——
24	Fe^{55}, Fe^{57}, Fe^{58}	3.83(6)	0.05	0.16	3.85 (5)	0.5	3.844 (15)	2.3	3.856	1.20	——	——	——	——	3.86	0.2
									3.792(6)	0.30	3.78	1.7	——	——	——	——
—	Fe^{57}	——	——	——	——	——	——	——	3.778(8)	0.30	——	——	——	——	——	——
26	Fe^{57}	3.66(6)	0.07	0.20	——	——	3.72 (2)	1.1	3.666(8)	0.20	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	——	——	——	——	——	——	3.54	4.8
28	Fe^{57}	★3.51(3)	0.14	0.41	——	——	3.55 (2)	?	3.504(7)	0.30	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	3.480(7)	0.50	——	——	——	——	——	——
27	Fe^{57}	3.42(2)	1.71	4.92	3.43 (3)	2.8	3.430 (15)	3.9	3.446(8)	2.20	——	——	——	——	——	——
									3.418(8)	2.50	——	——	——	——	——	——
—	Fe^{56}, Fe^{57}	——	——	——	——	——	——	——	3.360	0.50	3.36	1.5	——	——	——	——
—	?	——	——	——	——	——	——	——	3.325(8)	0.10	——	——	——	——	——	——
—	Fe^{57}, Fe^{58}	——	——	——	——	——	——	——	3.296(8)	0.50	——	——	——	——	3.29	0.5
—	Fe^{57}	——	——	——	——	——	——	——	3.27 (5)	1.70	——	——	——	——	——	——
28	Fe^{57}	3.23(3)	0.78	2.00	——	——	3.240 (15)	2.9	3.248(8)	0.40	——	——	——	——	——	——
									3.228(8)	0.50	——	——	——	——	——	——
—	Fe^{57}	——	——	——	——	——	——	——	3.192 (5)	1.00	——	——	——	——	——	——
—	Fe^{57}	——	——	——	——	——	3.15 (2)	2.1	3.172 (8)	0.80	——	——	——	——	——	——
29	Fe^{57}	3.12(3)	0.43	1.20	——	——	——	——	3.109 (8)	0.70	——	——	——	——	——	——
30	Fe^{55}, Fe^{57}, Fe^{58}	3.06(3)	0.21	0.61	——	——	——	——	3.082 (6)	0.50	3.07	4.6	——	——	3.06	3.1
—	Fe^{58}	——	——	——	——	——	——	——	——	——	2.98	1.0	——	——	——	——
—	Fe^{57}	——	——	——	——	——	——	——	2.955	0.70	——	——	——	——	——	——
31	Fe^{57}	2.84(4)	0.84	1.68	——	——	2.848 (12)	3.4	2.888 (8)	0.50	——	——	——	——	——	——
									2.838 (8)	0.80	——	——	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	——	——	——	——	——	——	2.70	10.3
32	Fe^{57}	2.72(3)	0.66	2.66	——	——	2.76 (10)	8.2	2.720 (8)	2.30	——	——	——	——	——	——
									2.698 (8)	0.80	——	——	——	——	——	——
33	Fe^{55}, Fe^{57}	★2.61(3)	0.36	1.03	——	——	2.67 (2)	1.0	2.682 (8)	0.50	2.67	1.5	——	——	——	——
											2.63	1.0	——	——	——	——
34	Fe^{57}	2.52 (3)	0.14	0.41	——	——	——	——	2.525 (8)	0.50	——	——	——	——	——	——
35	Fe^{57}, Fe^{58}	2.44(3)	0.21	0.61	——	——	——	——	2.471 (8)	0.30	2.47	2.4	——	——	——	——
—	Fe^{58}	——	——	——	——	——	——	——	——	——	——	——	——	——	2.43	2.3
36	Fe^{57}	2.10(4)	0.54	1.54	——	——	2.143 (10)	1.4	2.128 (2)	0.80	——	——	——	——	——	——

Table (1): ●★Ref. line in the Rel. Int. Deter. ◎Observed new lines
● Ref. line in E. Calib. ★Ref. line in the Rel. Peak-to-total Calc.

ray intensities have been normalized to 94.65 photons per 100 neutron captures following /3,5/, and I_γ per 100 neutron capture so also is given in (Table 1, for comparison with earlier investigators.

In order to determine the energy calibration of the present spectrometer, from Adyasevich et al. /3/ γ-ray lines indicated by closed cricles in table 1 were used for this purpose.

The remaining gamma-ray energies, as determined from the best fit calibration line, agree within experimental error to earlier values (as shown in table 1) and demonstrate the linearity of the system. It is noted that four of the gamma-rays which have No. (6,8,15 and 16) were unreported in previous (n,γ) measurements with natural iron sample while the identification of the remaining transitions agrees with that of earlier investigators.

4. DISCUSSION

There are four stable isotopes of iron, Fe^{56} accounts for approximately 93% of all the thermal neutron capture reactions in natural iron. The abundances /5/, cross-sections /5/ and contributions of these isotopes to the total cross-section are listed in (Table 2). The cross-section for the capture of thermal neutrons by natural isotope mixture /31/ is $\bar{\sigma}$ = 2.62±0.06b.

Table 2

Properties of Fe isotopes

Isotope	Fe^{54}	Fe^{56}	Fe^{57}	Fe^{58}
Contents in natural mixture %	5.84	91.68	2.17	0.31
Thermal neutron cross-section (b)	2.30	2.75	2.50	0.98
Isotope contribution to (%)	5.00	93.00	2.00	0.10
Neutron binding energy in product nucleus (keV)	9300±5[a] 9298±5[b]	7642±5[a] 7643±4[b]	10040±6[a] 10038±10[b]	6586±6[a]

a Ref. /30/ and b Ref. /5/.

The thermal neutron capture gamma-rays of samples enriched in Fe^{54} have been studied by Ikagami et al. [32] by the method of coincidences between a three crystal pair spectrometer and a single NaI(Tl) crystal spectrometer, and by Loskutova et al. [33] with the aid of a Compton recoil spectrometer. While Murzin et al. [34] investigated the capture gamma-ray spectra produced in a sample enriched in Fe^{57} and normal iron by the help of a three crystal pair spectrometer.

These measurements helped the assignment for most of the known capture gamma-rays of natural iron to individual isotopes. The present results will be compared with their reported measurements.

4.1 Contribution to the Gamma-Spectrum from Fe^{55} :

The 9.30 ± 0.02 MeV and 8.88 ± 0.02 MeV lines correspond to Fe^{55} transitions the capturing to the ground and first excited state [2,3,5,32,33]. Their absolute intensities are 56 and 6 respectively per 100 neutron capture in Fe^{54}.

The disapearance of the, 8.88 MeV gamma-ray in Fe^{55} spectrum was completely unexpected, for the 8.882 ± 0.006 MeV gamma-ray found by Groshev et al. [5] had previously been assigned to Fe^{55} because its energy fits closely the difference between the neutron binding energy 9.298 ± 0.005 MeV and the energy of the first excited state 0.414 MeV.

The gamma-ray lines with energies 6.86 ± 0.03, 6.27 ± 0.03, 5.74 ± 0.05 and 5.35 ± 0.02 MeV, coincides within the accuracy of measurement with the corresponding capture gamma-ray lines from samples enriched in Fe^{55} [33]. However bearing in mind the isotope contributions to the capture cross-section their intensities are 2%, 3%, 2.5% and 1.3% respectively per neutron capture in Fe^{54}.

The Fe^{55} gamma-rays [33] of energies 7.27, 4.46, 3.79, 3.07, 2.63, 2.67 and 2.47 MeV cannot be isolated since these gamma lines are concealed under the Fe^{57}, 7.28 ± 0.02, 4.48 ± 0.03, 3.83 ± 0.04, 3.04 ± 0.03, doublet 2.65 ± 0.04 and 2.44 ± 0.03 MeV gamma lines respectively.

While the Fe^{55} gamma-rays of energies 7.27, 5.50 and 3.07 MeV are concealed also under the Fe^{58} [34], 7.26, 5.50 and 3.08 MeV gamma lines respectively.

The doublet 6.27±0.03 MeV was well resolved by Groshev et al.[5] into 6.295±0.008 MeV ($I_\gamma \simeq 2\%$) and 6.269±0.008 MeV ($I_\gamma \simeq 2\%$). It can be concluded that the sum of intensities of these two lines ($I_\gamma \simeq 4\%$) is equivalent within the accuracy of measurements to the corresponding intensity in Fe^{55} (3% [33]), and hence the gamma line 6.295±0.008 MeV detected by Groshev et al.[5] can be assigned to Fe^{55}. The 6.295±0.008 MeV gamma line match the energy difference of the capturing state [25] 9.298±0.005 MeV and the level 2.987±0.008 MeV in Fe^{55} populated in (d,p) reaction in reference [16].

Peak number (15) which correspond to 5.35±0.02 MeV agrees well with 5.37 MeV peak defined by Loskutova et al. [33] from the reaction $Fe^{54}(n,\gamma)Fe^{55}$. This represents a previously unobserved peak in thermal neutron capture studies in natural iron.

The weak gamma-ray number (8) at 6.75±0.03 MeV cannot arise from the capture of scattered neutron in the apparatus. This is born out by the background spectrum which was taken with a sample of Pb substituted for the iron [26]. Neutron capture in the iodine of the sodium iodide of the crystals should give rise to gamma-rays with energies of 6.45 and 6.71 MeV [35]. Other known capture gamma-rays with energies of [4] 6.75 MeV have been ruled out by the nonappearance of accompanying gamma-rays with other energies. Hence peak number (8) is also expected to originate in Fe^{55} because it has the proper energy to populate a level at 2.548±0.030 established from nuclear reaction studies [16,36-38]. Lopkewicz et al. [39] assigned gamma-rays of energy 2.52±0.07 MeV from Fe^{55} in (p,n) reaction which probably represents the ground-state transition from the 2.544±010 MeV level. This represents previously unobserved transition in thermal neutron capture studies of Fe^{55}.

The Fe^{55} gamma transitions from the capturing state are practically all to the levels for which the orbital momentum $l_n=1$ is established in the (d,p) reaction, i.e. they all correspond to E_1 transition. But in the capture of reasonance neutrons [40] with the energy of 0.052 MeV there have been established besides the transitions to the levels with $I_n=1$ transitions to 0.933 MeV and 1.413 MeV, and for the first of these it has been found that $l_n=3$. Putting this observation into consideration Groshev et al. [5] concluded that neutrons with orbital momenta $l_n > 1$ are captured.

The levels of Fe^{55} have been investigated in the $Mn^{55}(p,n)Fe^{55}$ reaction [41,42] $Fe^{54}(d,p)Fe^{55}$ reaction [25] and in the decay of the ground state $7/2^-$ of Co^{55} to Fe^{55} [25].

4.2 Contribution to the Gamma-Spectrum from Fe^{57} :

The highest peak number (4) which corresponds to 7.63 ± 0.02 MeV is a doublet which has been well resolved by Groshev et al. [5] and represents two transitions, to the ground state and to 14 keV in Fe^{57}. The investigation of circular polarization of 7.643 MeV gamma-ray in the capture of polarized neutrons by Fe^{56} has shown that the intensity of the transition of the ground state amounts to $49\pm19\%$ of the total intensity of both transitions [17]. This has been verified by Groshev et al. [5] who found the intensities of the transitions to the ground state and the first excited level to be equal accurately to within 10%.

Peak number (5) corresponds to a gamma-ray with an energy of 7.28 ± 0.02 MeV. Coincidence spectrum with the 7.285 MeV gamma-ray determined by Fiebiger et al. [6] which populates 0.366 MeV level showed peaks of 0.22 and 0.36 MeV which correspond to transition from the 0.366 MeV level to the 0.136 and 0.014 MeV level respectively with relative intensities of 18 ± 3 and $82\pm3\%$.

Peak number (9) of energy 6.44 ± 0.03 MeV corresponds to the 6.379 ± 0.007 MeV gamma-ray line determined by Groshev et al. [5] which

corresponds to a transition from the capturing state to 1.264 excited state of spin and parity $(3/2^-)$.

The next incompletely resolved doublet of peaks corresponds to gamma-ray energies of 6.04±0.02 MeV and 5.93±0.02 MeV. These are identified with the reported 6.018±0.005 MeV and 5.920±0.005 MeV gamma rays of normal iron [5]. The gamma-ray lines with energies, 4.96±0.02, 4.81±0.02, 4.68±0.02, 4.48±0.02, 4.40±0.02 doublet 4.20±0.03, 4.00±0.02, doublet 3.83±0.04, 3.66±0.04, 3.51±0.03 doublet 3.42±0.02, group of peaks 3.22±0.03, 3.13±0.03 doublet 2.84±0.04, doublet 2.72±0.03, 2.65±0.03, 2.52±0.02, 2.44±0.03 and 2.18±0.04 MeV coincide within the accuracy of measurement with the corresponding capture gamma-ray energies given by Groshev et al. [5]. Also their intensities per 100 neutron capture show good agreement with Groshev's values to within the allowable error. The gamma-ray transition scheme is well defined in [5]. Our present gamma-ray energies agree satisfactory with the values represented in the previously mentioned gamma transition scheme.

Since E_1 transition predominate in the de-excitation from the capturing state produced in a thermal neutron capture, levels with $l_n=1$ are mainly in evidence in the process of de-excitation. Direct transition from the capture state in Fe^{57} excite levels with characteristics $(1/2^-),(3/2^-)$. In these decay to low levels $(1/2^-),(3/2^-)$ and $(5/2^-)$ M_1 and E_2 transitions must be observed. For energies of 2 to 3 MeV M_1 transitions are by the Veisskopf estimate more probable than E_2 by two orders of magnitude.

Nevertheless in Fe^{57} all low levels have negative parity and angular momenta 1/2, 3/2, 5/2 and 7/2 ($l_n=1$ and 3). Positive parity levels ($l_n=0$ and 2) lie at comparitively high excitations.

Peak number (18) of energy 5.18±0.02 MeV may correspond to a transition in Fe^{57}, for this it must populate a level at 2.463±0.020 MeV which correspond to the energy of peak number (35) of energy 2.44±0.03 MeV, and may be the level of 2.456±0.008 MeV established in

the (d,p) reaction and other nuclear reaction [16,43,44]. However, the absolute intensity of this 5.18 MeV gamma-rays is very small nearly 0.1% per neutron capture.

4.3 Contribution to the Gamma-Spectrum from Fe^{58} :

The very weak 10.038±0.008 MeV line which corresponds to the Fe^{58} neutron binding energy defined by Groshev et al. [5] and also references [2,34] is not statistically identified in the present work.

Peak number (3) of energy 8.34±0.03 MeV coincides within the accuracy of measurement with the transition to the second excited state (2^+) from the capture state in Fe^{58}.

No transition from the capturing to the first excited state (2^+) with 0.8 MeV is observed in the present work and also in [34]. Moreover in the spectrum there are the well resolved gamma lines of energy 6.95±0.02 and 5.50±0.02 MeV which correspond to transitions from the capture state to 3.08 and 4.54 MeV states defined in nuclear reactions [16,44,45].

However the Fe^{58} gamma rays of energies [34] 7.26, 3.86, 3.54, 3.08 and 2.42 MeV can not be isolated since these gamma lines are concealed under Fe^{55} and Fe^{57} gamma lines of energies 7.28±0.02, 3.83±0.04, 3.51±0.03, 3.04±0.03 and 2.44±0.03 MeV.

The intensity of peak (14) of energy 5.50±0.02 MeV has been defined by reference [34] to be equally distributed between the radiating isotopes of Fe^{55} and Fe^{58} present in the natural sample. Also reference [34] canceled the 5.787 MeV peak to belong to the radiative isotope Fe^{58}.

The peak number (6) of energy 6.95±0.02 MeV was observed for the first time in the capture gamma-rays spectrum from natural iron. Nevertheless it is well defined in $Fe^{57}(n,\gamma)Fe^{58}$ [34]. It is possible that this line represents a doublet of energies very close to each other [34].

5. CONCLUSION

The features of this iron spectrum Fig. 7 is in complete accord with previous results of Kinsey et al. [2] Adyesevich et al. [3] and Groshev et al. [5] and others [6]. It gives lines at : 6.95, 6.75, 5.35 and 5.18 MeV, which were previously unobserved in thermal neutron capture studies of natural iron, in addition to most of the all-ready reported gamma-ray lines. The intensities of gamma-ray lines per neutron capture in natural iron is found to agree with a good appro i-mation with the previously measured values.

Due to the very low Fe^{58} contribution to 6 of natural iron, it has not been possible to assigne any gamma-ray line to Fe^{59}. All the spectrum lines is contributed to the three other isotopes as has been previously represented in the discussion.

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