RELATIVE INTENSITIES OF GAMMA RAYS IN BETA DECAY OF Pt^{199}

by

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INTRODUCTION

Since naturally occurring platinum metal has six stable isotopes, radioactive isotopes having several different half-lives are produced when natural platinum captures slow neutrons. The assignment of 31-minutes, half-period activity to Pt^{199} was first made by McMillan et. al. (1) in 1937. The radioactive Pt^{199} is produced when stable Pt^{199} captures slow neutrons, which then decays by electron emission to nuclear energy levels in Au^{199}. Subsequent gamma ray emission produces Au^{199} in its ground state. However, the ground state of Au^{199} is not stable, and decays by electron emission (2) to nuclear levels in Hg^{199}. The half-period of this decay is 3.2 days.

The beta decay of Pt^{199} was studied in some detail by Le. Blanc et. al. (3) employing a 180° magnetic photographic spectrometer and a NaI (Tl) scintillation spectrometer. Later Joshi et. al. (4,5) used NaI (Tl) and anthracene scintillation spectrometers and a lens type magnetic spectrometer in coincidence arrangement in their study of Pt^{199} decay. More recently Black (6) has used a Ge(Li) solid state detector in his investigation of the gamma rays emitted in beta decay of Pt^{199}.

A summary of the gamma ray energies and their relative intensities from previous work (3,5,6) is given in Table 1.

It is seen from Table 1. that eleven new gamma rays were found by Black (6) which were not detected earlier (3,5). There is also slight disagreement between the relative intensities of the gamma rays found by the two groups (5,6). A gamma ray of energy 197 keV is reported by two groups (3,5) and a gamma ray of energy 186 keV is reported by the third investigator (6).

The principal aims of the present investigation of the beta decay of Pt^{199} are as follows:

Table 1.

Relative intensities of gamma rays in the beta decay of Pt^{199}. Gamma ray energies are in keV. Relative intensities are given in parentheses.

Ref. 3	Ref. 5		Ref. 6	
---	---		55	(no photons found)
74	X-rays + 75	(38)	75	
197	197	(38)	186	(40.1)
---	---		219	(2.2)
---	---		226	(3.0)
246	245	(16)	246	(16.3)
318	320	(33)	317	(35.8)
---	---		417	(1.4)
---	---		425	(2.3)
---	---		467	(12.6)
475	475	(48)	474	(9.9)
---	---		494	(38.0)
540	540	(100)	543	(100.0)
---	---		644	(0.6)
---	---		665	(1.2)
715	715	(14)	715	(12.2)
790	790	(10)	791	(7.6)
---	---		836	(1.4)
---	---		889	(2.1)
960	960	(8)	967	(6.3)

To see whether the eleven new gamma rays reported by Black (6) are indeed present.

To check the half-lives of all the gamma rays. All of the gamma rays in the decay of Pt^{199} should have a half-period of 31 minutes. This step is very important. Many examples are found in which gamma rays were assigned to wrong isotopes due to neglect in following the half-life.

To measure accurately the relative intensities of the gamma rays.

To find out whether both of the gamma rays of energies 197 and 186 keV are present, or only one of them is present.

With these aims in sight, high resolution Ge(Li) solid state detectors are employed in the present experiment. The radioactive Pt^{199} was produced by slow neutron capture by platinum metal which is enriched in Pt^{198} isotope. Irradiation of slow neutrons was done in the Triga Mark II reactor at Kansas State University.

INTERACTION OF GAMMA RAYS IN Ge(Li) DETECTOR

Ge(Li) Detector:

A lithium drifted Germanium detector (usually called a Ge(Li) detector) is basically a solid state ionization device which converts ionization produced in the crystal into an electric pulse. Such a detector is formed by drifting lithium into a p-type germanium crystal (7). This process produces a heavily doped n-type front surface, a central region called an intrinsic region, and a p-type back surface. This arrangement is technically known as a p-i-n structure. A voltage gradient of the order of 50-100 volt/mm is applied across the two surfaces. A schematic diagram of a Ge(Li) detector is shown in Plate I. Interaction of photons within the intrinsic region creates high speed electrons which lose their energy by producing free charge carriers (electron-hole pairs). Under the action of applied voltage gradient, their charges are collected producing a charge pulse. These charge pulses are proportional to the energies of the photons.

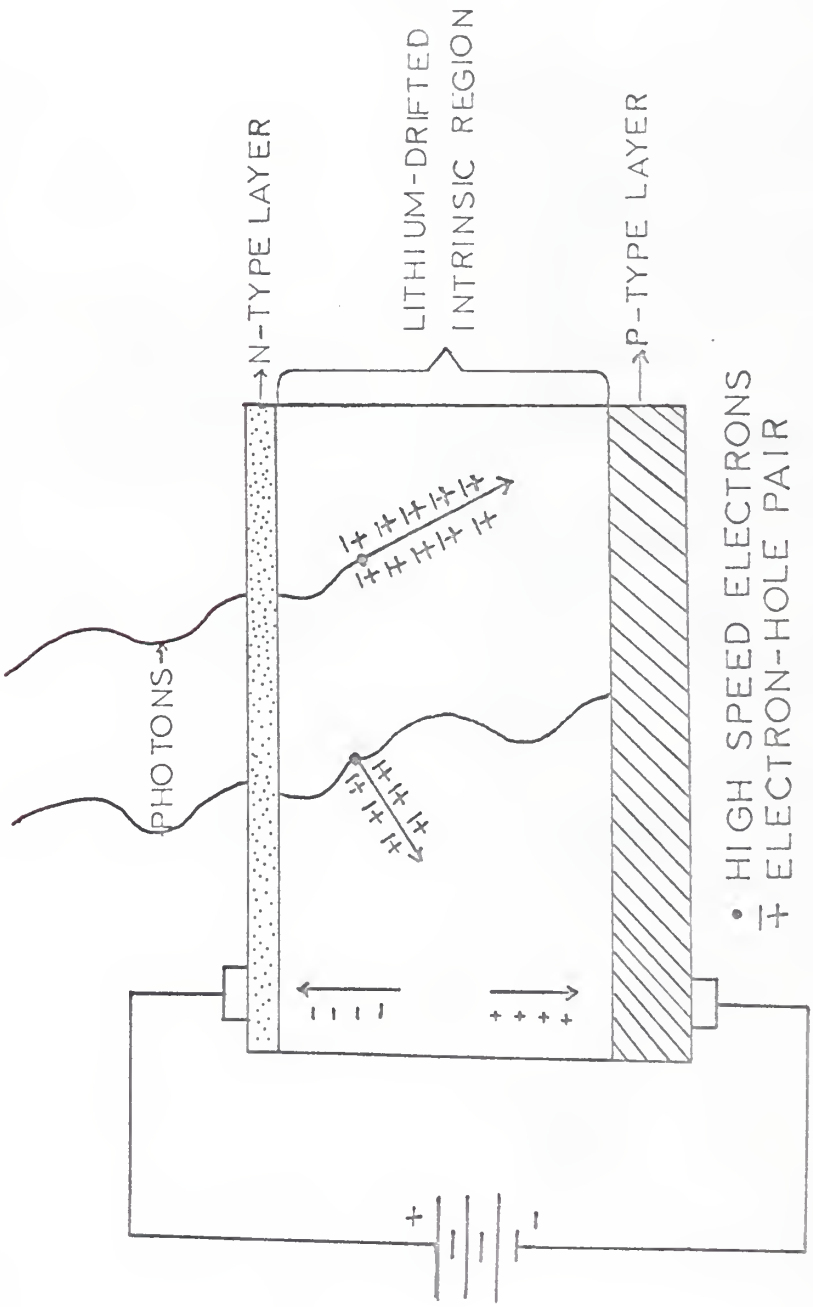
There are twelve ways (8) by which gamma rays can interact with any matter including a Ge(Li) detector. However, only three modes are most important over an energy interval of about 5 Kev to 5 Mev. Gamma rays found in radioactive decay have generally energies within this energy range. These three processes are photo electric effect, Compton scattering, and pair production.

The major features of a differential pulse-height spectrum of gamma rays (sometimes called a singles spectrum) are produced when incident photons interacting by the above three modes give up all or a part of their energy producing charge pulses in the Ge(Li) detector.

EXPLANATION OF PLATE I

Schematic diagram of a lithium-drifted germanium detector.

PLATE I


N-TYPE LAYER
LITHIUM-DRIFTED
INTRINSIC REGION
P-TYPE LAYER
PHOTONS
• HIGH SPEED ELECTRONS
+ ELECTRON-HOLE PAIR
+
-

Photoelectric Effect:

In this interaction, the entire photon energy is absorbed by a bound electron. The gamma ray energy then appears as the kinetic energy of that electron as it is ejected from the atom and an X-ray or Auger electron emitted by the residual atom. The cross section for this process is proportional to Z^5 and increases rapidly with decreasing photon energy. Here, Z is the atomic number of the intrinsic layer material. The low energy X-ray is invariably absorbed in a second photoelectric encounter before it can escape from the crystal. As a result, the total photon energy appears as electron kinetic energy.

Compton Scattering:

In this process the incident photon is scattered by a free electron with partial energy loss which depends on the angle of scattering. The kinetic energy of the electron lies between zero and an upper energy limit which is a function of the incident photon energy. This type of scattering gives rise to a continuous electron distribution between these limits. The cross section for this process is proportional to Z and is not as highly energy dependent as photo electric effect.

Pair Production:

The above two processes are possible with varying probability for all energies of incident photons. However, the pair production process has an energy threshold at which this mode starts. This threshold has a value of 1.022 Mev which is equal to the combined positron-electron rest mass. Above this energy threshold, the cross section for this process is proportional to Z^2. In the pair production encounter all of the gamma rays energy is absorbed and appears as the total kinetic energy of the positron-electron pair (E_γ - 1.022 Mev) plus the rest mass of the pair. Here E_γ is the

energy of the incident photon. The pair will lose its kinetic energy in further interactions. The positron which is unstable will eventually annihilate with an atomic electron producing two photons each of energy 0.511 Mev. These two photons are emitted 180° to each other. If both of these photons are also absorbed in the detector a full energy peak will appear at E_γ. One or both of these photons escaping from the detectors without further interactions will produce two satellite peaks at (E_γ - 0.511 Mev) and (E_γ - 1.022 Mev), respectively.

The details of these three processes are discussed in detail elsewhere (8). The variation of absorption cross section with photon energy in germanium is shown in Plate II. A typical gamma ray spectrum:

The above mentioned three interaction processes in a Ge(Li) detector will generate a differential energy spectrum of gamma rays. The energy spectrum for every monoenergetic gamma ray of energy E_γ will have the following charachteristics.

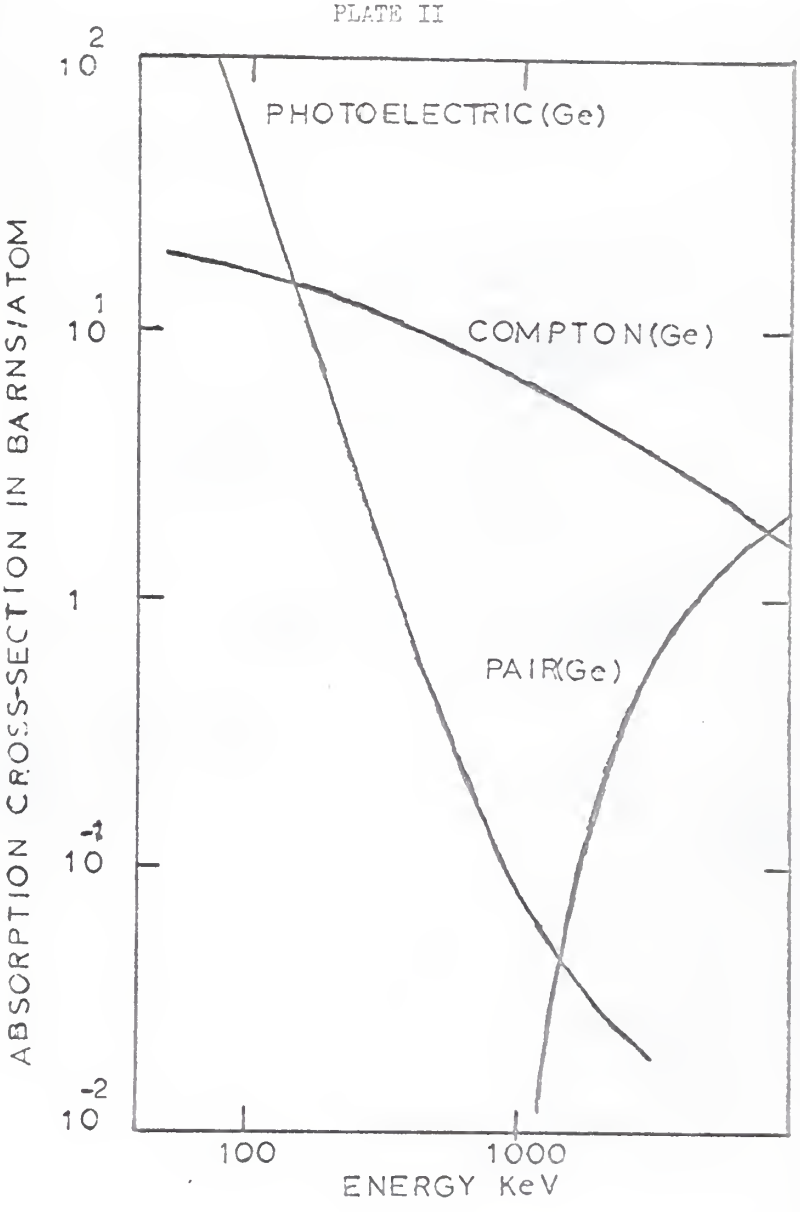
There will be a "photopeak" at energy E_γ corresponding to total absorption of gamma ray. Multiple processes also will contribute to this peak as much or more than the photoelectric encounter. Such multiple events are Compton scattering, followed by a photoevent, and pair production, in turn followed by the complete absorption of the two annihilation quanta. Therefore, the peak at E_γ is known as "full energy peak". The contribution of multiple processes to the full energy peak is determined by the size of the detector, source geometry and also on the energy of the gamma ray.

Corresponding to each full energy peak at E_γ, there will be a Compton distribution which will result when the Compton electrons are absorbed and the scattered photons escape the detector. For the maximum energy of the Compton electrons the pulse absorbed is known as the Compton edge. There

EXPLANATION OF PLATE II

Variation of the photoelectric, Compton, and pair-production cross sections in germanium as a function of gamma ray energy.

PLATE II


ABSORPTION CROSS-SECTION IN BARNS/ATOM
10^{2}
10^{1}
1
10^{-1}
10^{-2}
PHOTOELECTRIC(Ge)
COMPTON(Ge)
PAIR(Ge)
100
1000
ENERGY KeV

will also be a peak called "back scattered peak" superimposed on the rather flat energy distribution of Compton electrons, which extends to zero energy.

If E_γ is greater than 1.022 Mev, in addition to the above distributions, other satellite peaks appear for each full energy peak at E_γ. If one of the annihilation quanta escapes the detector after the pair production encounter, a peak will appear at an energy (E_γ - 0.511 Mev). If both of the annihilation quanta escape detection another peak will appear at an energy (E_γ - 1.022 Mev). There will also be a peak at 0.511 Mev corresponding to annihilation quanta which are produced after pair production event.

In addition to the above distributions there will usually be a continuous bremsstrahlung radiation produced by electrons of beta decay going through any intervening absorber between the source and the detector. This absorber is necessary to stop beta rays reaching the detector and being counted by the detector.

A schematic diagram of a singles spectrum of a gamma ray of energy E_γ Mev is shown in Plate III.

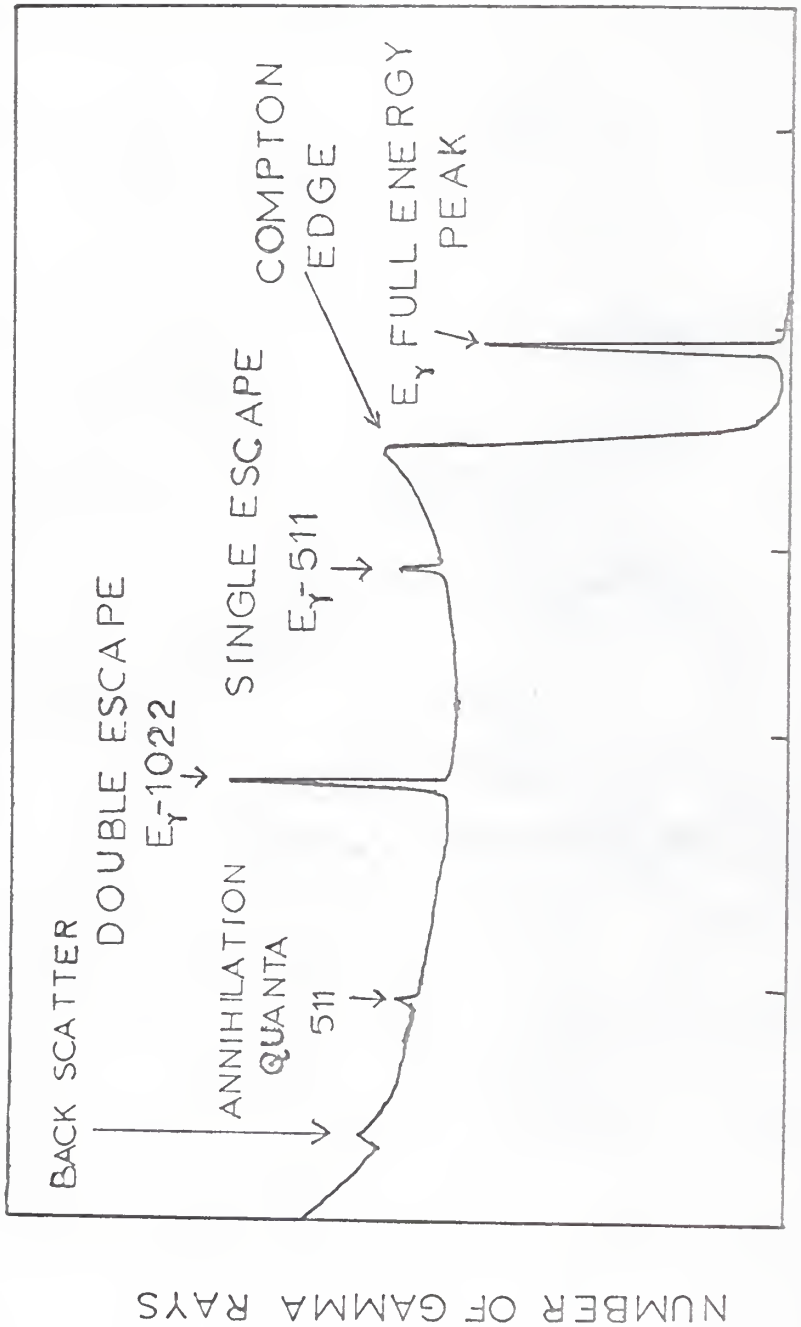
When there are numerous gamma rays, each gamma ray would have an energy spectrum like that of Plate III. Because of this the actual spectrum will be very complicated. However, the full energy peak corresponding to each gamma ray usually stands out distinctly, if the energy resolution of the detector is good.

The resolution for the Ge(Li) detector is measured in terms of the full width at half the maximum height of the full energy peak. It is written as FWHM. The smaller the FWHM is, better the resolution is. The intensity of any gamma ray is proportional to the area under the full energy peak. The full intensity of the gamma ray would correspond to the area under the full

EXPLANATION OF PLATE III

A typical singles spectrum of a gamma ray of energy E is shown.

PLATE III


BACK SCATTER
DOUBLE ESCAPE
E_γ-1022
ANNIHILATION QUANTA
511
SINGLE ESCAPE
E_γ-511
COMPTON EDGE
E_γ FULL ENERGY PEAK
0
500
1000
1500
2000
2500
ENERGY OF GAMMA RAY (KeV)
NUMBER OF GAMMA RAYS

singles spectrum of Plate III, for every gamma ray. For a complicated spectrum this would be difficult to resolve for each gamma ray. To get around this difficulty, a ratio called peak to total ratio is experimentally measured for a given detector and given source geometry, by employing monoenergetic gamma ray sources. This ratio is then used to get the full intensity of each gamma ray in complicated spectrum.

EXPERIMENTAL SET-UP

The experimental set-up used for detection of gamma rays in this experiment consists of (a) the Detector-Dewar System, (b) Electronics, and (c) Ge(Li) detector.

(a) The Detector-Dewar System:

A bias voltage of -400 volts is maintained across the two faces of the detector manufactured by SSR and +400 volts for the detector manufactured by Isotopes, Inc. In order to reduce the detector leakage current, they were operated at liquid nitrogen temperature (77°K). Also, the detectors were kept in vacuum to avoid condensation and contamination of the detector surface. The Isotope detector is mounted on a cold finger in contact with liquid nitrogen. Liquid nitrogen is contained in a dewar which has capacity of 25 liters. The whole system is kept inside a steel container, forming a detector-dewar system. The same kind of precaution was taken also for the SSR detector.

In the case of the Isotopes detector, the distance between the detector and the steel window is 0.47 cm. The steel window is 0.025 cm thick. Unfortunately, it acts as an absorber to the incident gamma rays of low energy. There was no such difficulty for the SSR detector which has an aluminum window. Schematic diagram of the detector-dewar system is shown in Plate IV.

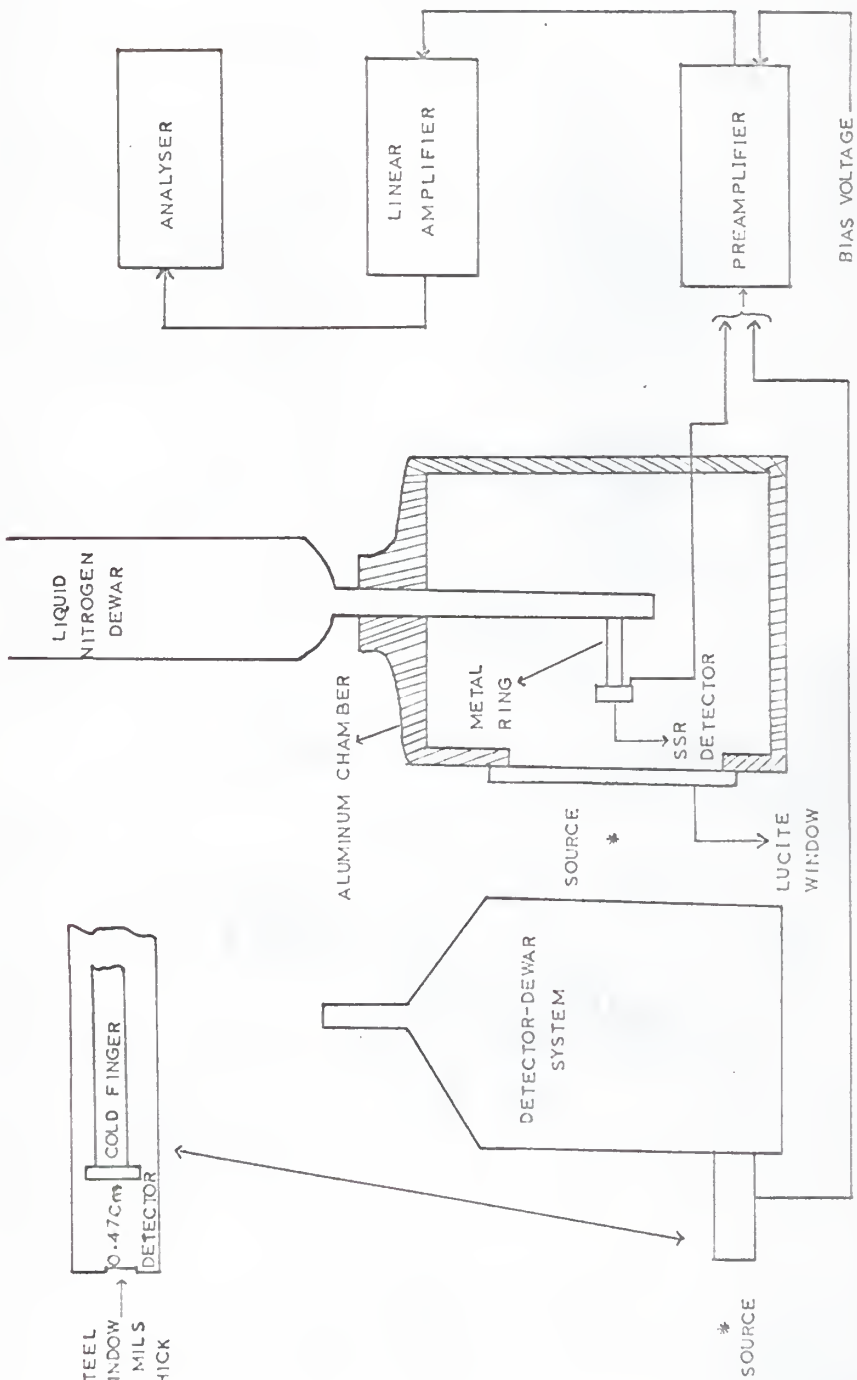
(b) Electronics:

The electrical pulses produced in Ge(Li) SSR detector were first amplified in a low-noise charge preamplifier: Tennelec Model TC 130. It has a charge sensitivity of 5 mv/Mev loss in a Ge(Li) detector, according to specifications. Also for the Isotopes detector a T M C FET preamplifier was

EXPLANATION OF PLATE IV

Block diagram showing the apparatus and the electronics used in accumulating singles spectra for both detectors.

PLATE IV


ANALYSER
LINEAR AMPLIFIER
PREAMPLIFIER
BIAS VOLTAGE
LIQUID NITROGEN DEWAR
METAL RING
SSR DETECTOR
ALUMINUM CHAMBER
SOURCE
LUCITE WINDOW
DETECTOR-DEWAR SYSTEM
COLD FINGER
0.47cm
DETECTOR
STEEL WINDOW 10 MILS THICK
SOURCE

used. It has a charge sensitivity of 350mv/Mev in a Silicon detector with normal setting and a 1.0-picrofarad feed-back capacity.

The signal was further amplified by a linear amplifier, Tennelec Model TC 200. This amplifier has RC pulse shaping and a total amplifier gain of 4 to 2048 with an integral nonlinearity of less than 0.05 per cent of rated output as given by the manufacturer's specifications.

The pulses were finally registered according to energy by a pulse-height Analyzer. The Analyzer was a 4096-channel Multiparameter pulse Analyzer with Model 213 Pulse Height Logic Units. This analyzer system has a differential linearity of 2 per cent of full scale, a time stability of less than 0.5 per cent of full scale channel drift per 30° centigrade and can accept as many as 5×10^4 counts per second with no change in drift or linearity, according to specifications.

A block diagram of the electronics is also shown in Plate IV.

(C) The characteristics of the two Ge(Li) detectors used are given in Table 2.

EXPERIMENTAL PROCEDURE

Source Preparation:

Radioactive Pt^{199} is produced when slow neutrons are captured by stable Pt^{198}. Many unwanted impurities will be produced if naturally occurring platinum metal is used. Table 3. gives the isotopic composition (9) of naturally occurring platinum metal. Table 3. also lists the impurities that will be produced by slow neutron capture, half-periods and the intense gamma rays emitted by their decay. By choosing the exposure time of 30 minutes in the reactor, the contribution of impurities can be reduced. Further reduction of these interfering activities can be achieved by using a sample of platinum metal which has been enriched in the Pt^{198} isotope.

In the present experiment a few milligram quantities of platinum metal, isotopically enriched in Pt^{198} were used to produce Pt^{199}. Enriched samples were purchased from Oak Ridge National Laboratories. The isotopic composition of the source used is given in Table 4. Although, the percentage of Pt^{194} and Pt^{195} is reduced from natural sample, the percentage of Pt^{196} is more than in the natural sample. However, the percentage of Pt^{198} in this sample is increased. Due to short time of exposure (30 minutes), contribution of Pt^{197} is expected to interfere the most.

Since Au^{199}, the daughter in the beta decay of Pt^{199} is itself radioactive (half-life 3.2 days), its interference will increase with time. Hence in determining the relative intensities of gamma rays in the beta decay of Pt^{199} correction for the impurity gamma rays may be necessary.

The sources were deposited between two Scotch tapes.

Geometry of Source:

For the case of the SSD detector, the source was fixed in front of the

Table 2.

Characteristics of Ge(Li) Detectors

Manufacturers	Area	Depletion Depth	Dead Layer	Case Thickness	Resolution	Bias Voltage
SSR[a]	1cm^2	4.2mm.	0.3mm. Ge window	0.381mm Al	3.8Kev FWHM	-400volts
Isotopes, Inc.[b]	8cm^2	5mm.	0.1mm. Ge window	0.254mm	5.04Kev FWHM	+440volts

[a]Solid State Radiations, Inc., 2261 South Carmelina Avenue, Los Angeles 64, California.

[b]Isotopes, Inc., 123 Woodland Avenue, West Wood, New Jersey 07675.

Table 3.

Characteristics of radioactive platinum isotopes produced when naturally occurring platinum metal captures slow neutrons.

Isotope of Platinum	Natural Percentage Abundance	Radioactive Isotope Produced by Slow Neutron Capture	Half Life of Isotope in Column Three	Intense Gamma Rays Emitted in the Decay of Isotope of Column Three
Pt^{190}	0.0127	Pt^{191}	3.0 days	13, 35, 41, and 54 keV
Pt^{192}	0.78	Pt^{193} isomeric state	4.4 days	135 and 127 keV
		Pt^{193} ground state	500 years	No gamma rays
Pt^{194}	32.9	Pt^{195} isomeric state	4.1 days	31, 99, 129, and 130 keV
Pt^{195}	33.8		Stable	
Pt^{196}	25.2	Pt^{197} isomeric state	78 minutes	346 keV
		Pt^{197} ground state	18 hours	77.3, 191, and 279 keV
Pt^{198}	7.19	Pt^{199} isomeric state	14.1 seconds	32 and 393 keV
		Pt^{199} ground state	30 minutes	Under present study

Note: Data of this table was taken from reference 2.

Table 4.

Isotopic composition of the platinum metal sample used in the present experiment.

Stable Isotope	Percentage Abundance
Pt^{190}	0.05
Pt^{192}	0.05
Pt^{194}	5.82 + 0.05
Pt^{195}	13.65 + 0.05
Pt^{196}	36.17 + 0.1
Pt^{198}	44.36 + 0.1

Note: Data of this table were supplied by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

detector and right on the face of the lucite window. The function of this lucite window is to absorb all the beta rays from the source. The thickness of the lucite absorber was 6.1mm. This absorber absorbs beta rays of the order of 2.0 Mev. The distance between the source and the detector was 4.2cm. No other extra absorbers were used in this experiment.

While using the Isotopes detector the source was placed 11.2cm away from the 0.9cm thick lucite beta absorber. This Lucite absorbs beta rays of the order of 2.5 Mev. No other absorbers were used. The actual distance between Pt^{199} source and the detector was 12.6 cm.

Energy Spectrum of Gamma Rays:

A differential pulse height spectrum of gamma rays commonly called singles spectra were taken for Pt^{199} source using two different detectors at two different amplifier gains for low energy and high energy, respectively.

Plates VI and VIII show singles spectra of gamma rays from Pt^{199} for low energy and high energy portions, respectively, using SSR detector. They have been corrected by subtracting background radiations which were accumulated without the source for the same period of time and for each amplifier gain separately.

Likewise, Plates V and VII show singles spectra from Pt^{199} for low energy and high energy portions respectively, using Isotopes detector. Again these spectra are corrected for background.

The sources which were used for energy calibration of the spectrometer and the gamma rays emitted by them are given below.

Ba^{133} -- 80, 273, 302, 355, and 382 keV

Na^{22} -- 511 and 1276 keV

Bi^{207} -- 570, 1064, and 1771 keV

Co^{60} -- 1173 and 1333 keV

Ca^{137} -- 662 keV

Half-life Determination:

As long as the length for accumulation of data is very small compared with the half life of isotope; the midpoint of the true time interval serves well. However, if the time is not small (say, 1/4 of a half life or greater) then the midpoint does not very accurately represent the time for the accumulation of data. For a better time one should choose the time during the accumulation of data at which the instantaneous counting rate is equal to the average counting rate over the entire duration. The formula used was

$$T = t_1 + \frac{1}{\lambda} \ln \frac{\lambda t_2}{1 - e^{-\lambda t_2}}$$

Where t_1 = start time for the accumulation of data

t_2 = true time

T = the time to represent the accumulation of data

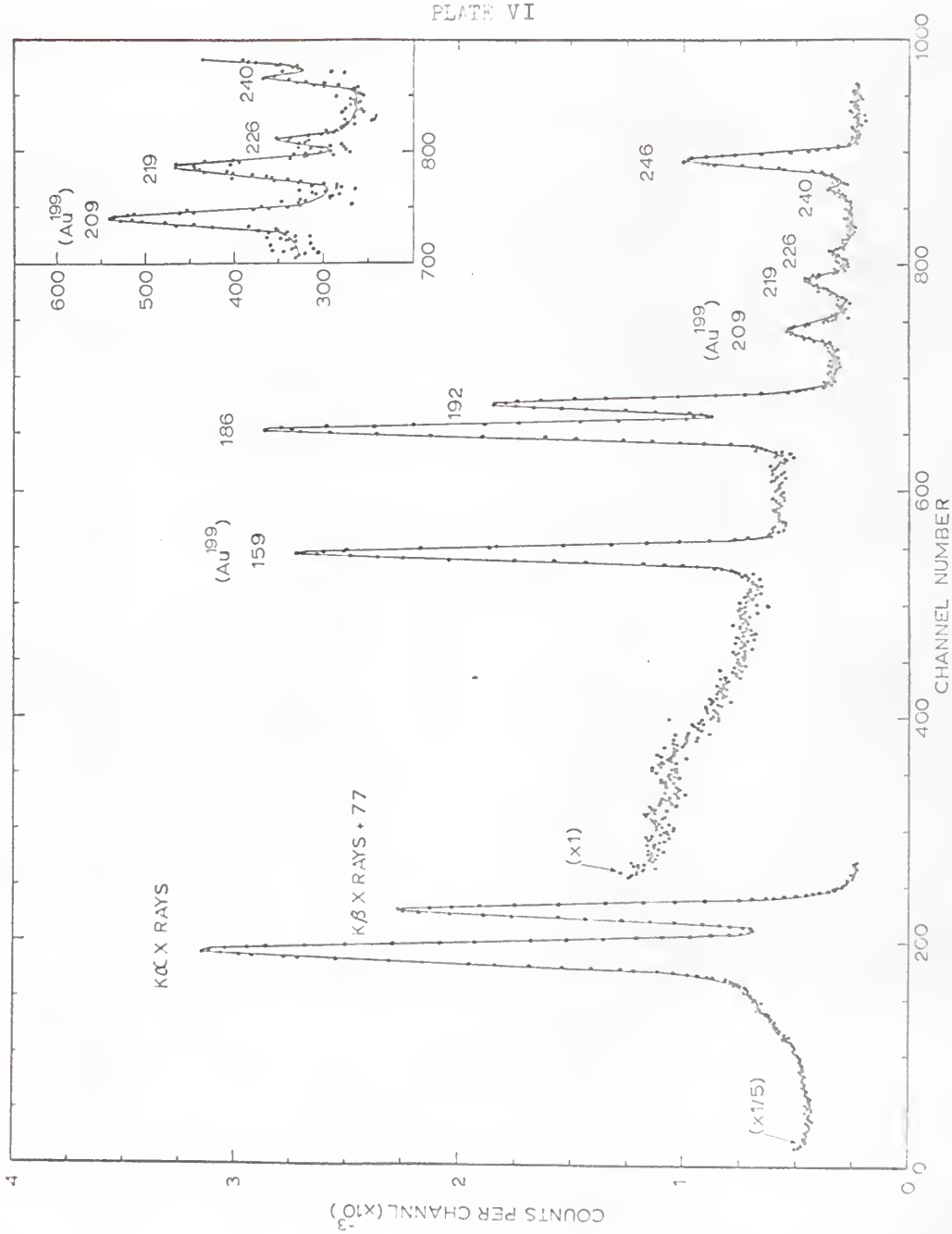
$\lambda = \frac{\ln 2}{T_{1/2}}$ = decay constant

To confirm whether the observed new gamma rays belong to Pt^{199} or not (if they have the 31 minute half-life or not) the accumulation of data is continued for 3 to 4 half lives of time. Normally the data is accumulated for a specific duration of time. Then after correcting for background the counts under the peak for each accumulation period are found. To find the half-life, the counting rates are plotted against the time on a semi-log graph paper. This gives a rough estimate of the half life. The data was processed in the computer by a least squares fitting procedure giving more accurate value of half-life. For a typical gamma ray of energy 543 Kev, both procedures of finding half-life are given in Plate IX.

EXPLANATION OF PLATE V

The low energy gamma ray spectrum of Pt^{199}. No extra absorbers were used between the source and the detector. The Isotopes detector was used in accumulating this spectrum.

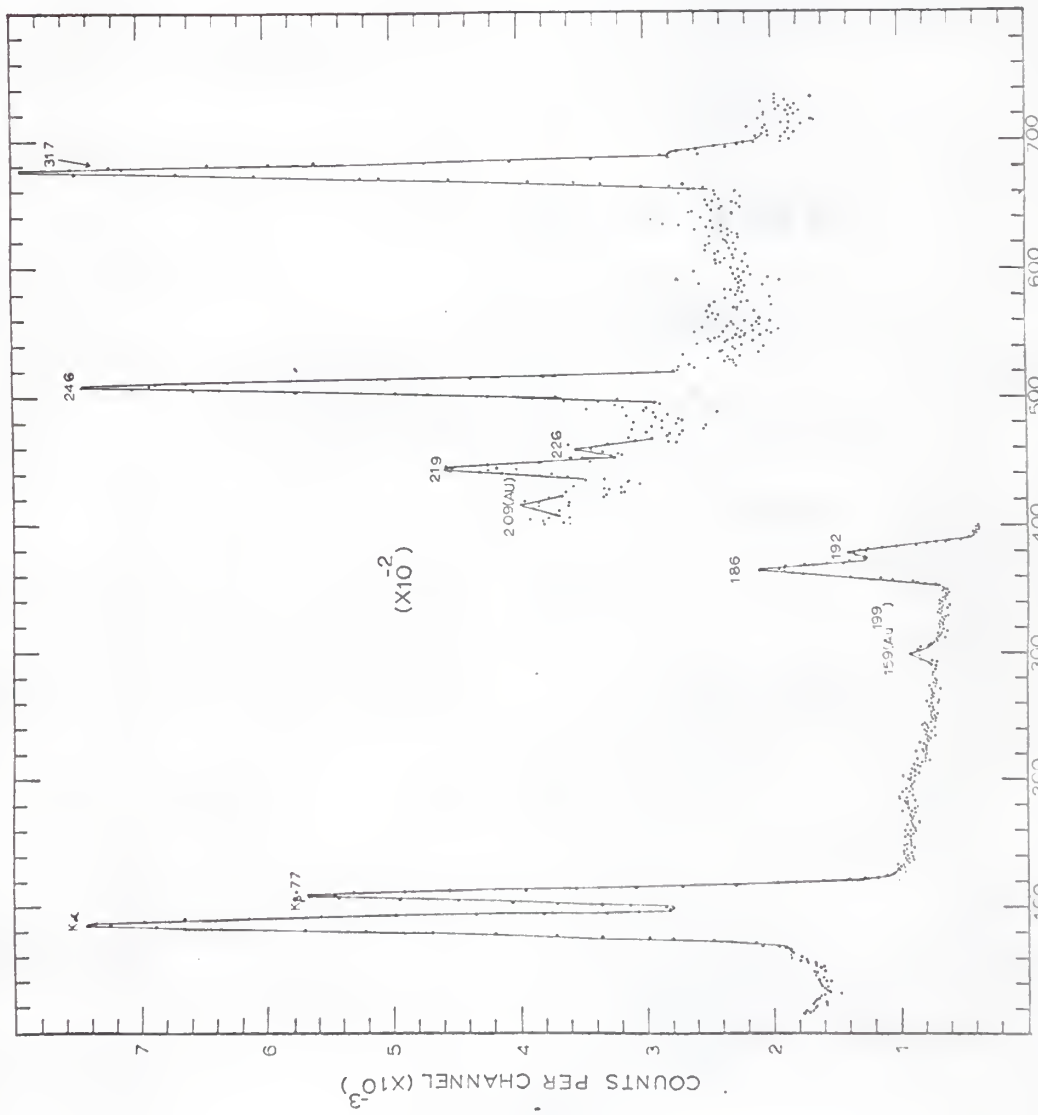
PLATE VI


COUNTS PER CHANNEL (x10³)
CHANNEL NUMBER
Kα X RAYS
Kβ X RAYS + 77
(Au¹⁹⁹)
159
186
192
209
219
226
240
246
(x1)
(x1/5)

EXPLANATION OF PLATE VI

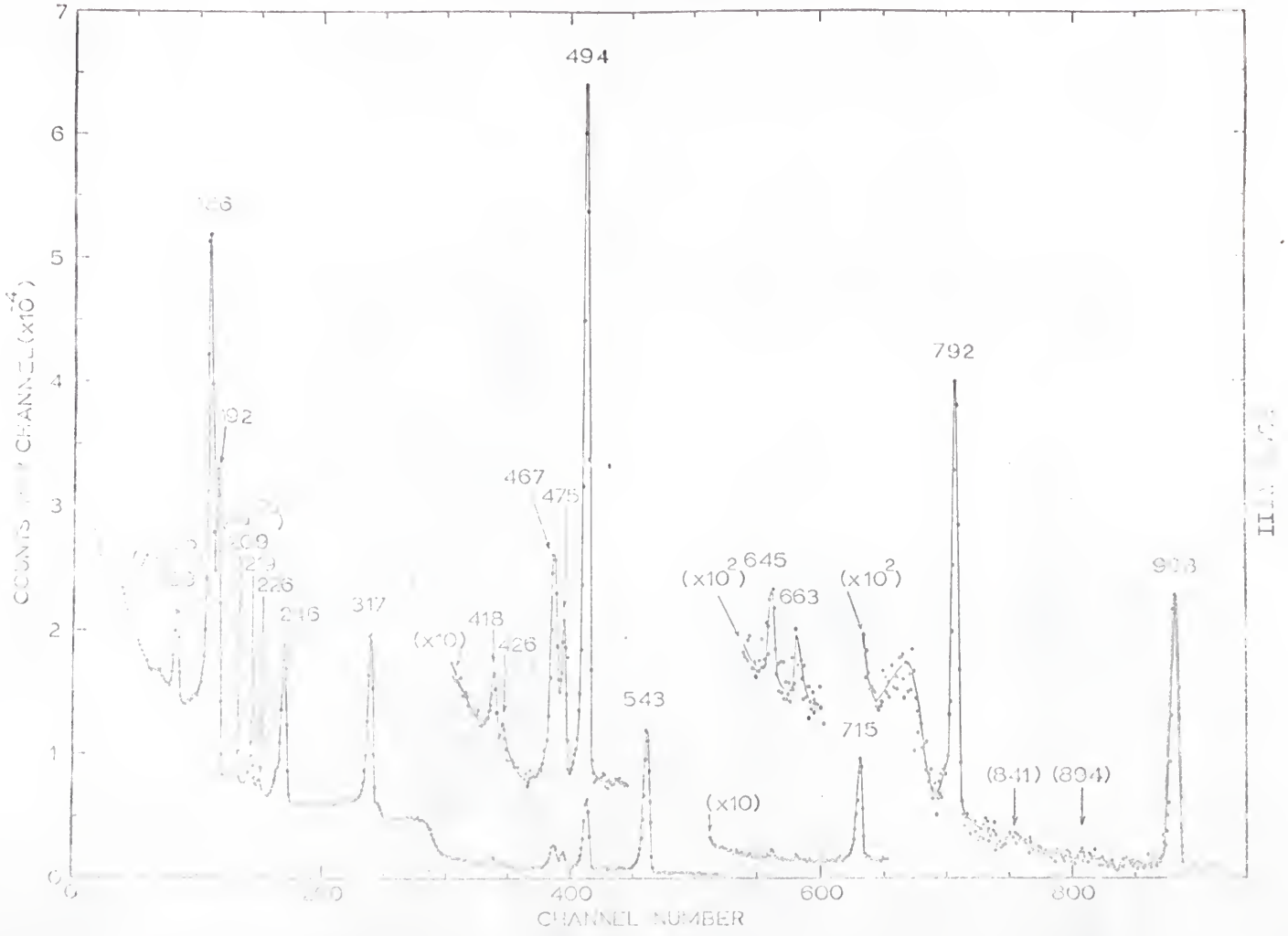
The low energy gamma ray spectrum of Pt^{199}. No extra absorbers were used between the source and detector. The SSR detector was used in accumulating this spectrum.

PLATE V


COUNTS PER CHANNEL (X10^{-3})
CHANNEL NUMBER
$(X10^{-2})$
Kα
Kβ+77
317
246
219
209(Au)
226
186
192
199
159(Au)

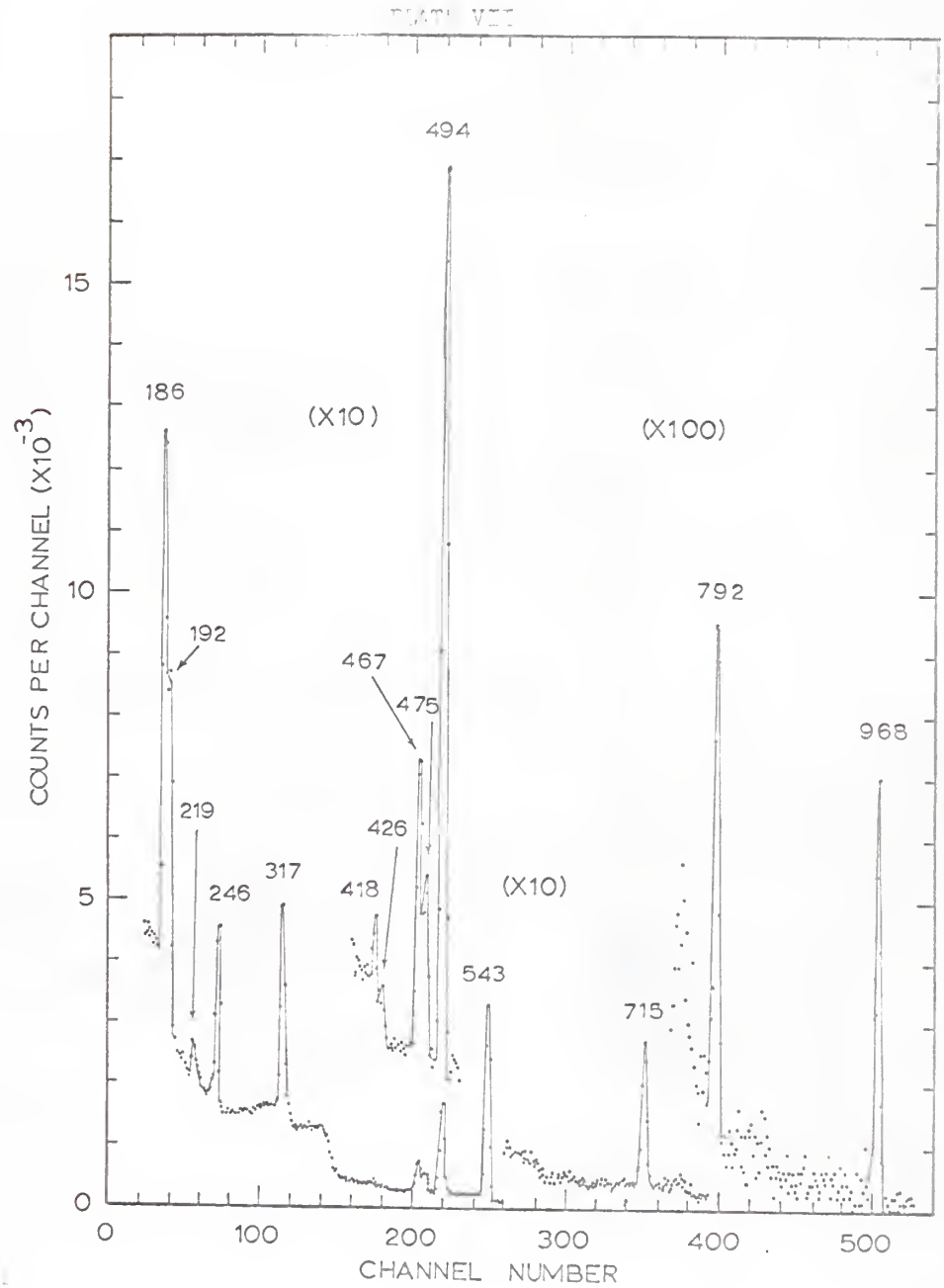
EXPLANATION OF PLATE VII

The high energy gamma ray spectrum of Pt^{199}. No extra absorbers were used between the source and the detector. The Isotopes detector was used in accumulating this spectrum.


494
792
467
475
645
663
(x10)
(x10)
(x10)
418
426
317
543
715
(841)
(894)
(x10)
400
600
800
CHANNEL NUMBER

EXPLANATION OF PLATE VIII

The high energy gamma ray spectrum of Pt^{199}. No extra absorbers were used between the source and the detector. The SSR detector was used in accumulating this spectrum.


494
186
(X10)
(X100)
792
192
467
475
968
219
426
317
246
418
(X10)
543
715
COUNTS PER CHANNEL (X10^{-3})
0
5
10
15
0
100
200
300
400
500
CHANNEL NUMBER

Apart from this normal procedure of finding half-life by least squares fitting, one sometimes encounters a mixture of gamma rays of the same energy but two different half-lives, which normally belong to two different isotopes. In such cases one has to follow at least 3 to 4 both half-lives.

In the present studies of Pt^{199}, it has been found that the 192 Kev gamma ray decays with at least two half-lives. To separate the two components at 192 Kev gamma ray, data was accumulated for about 54 hours. Then according to half-life determination procedure, which has been described above, the background subtracted counts were plotted on a semilog paper as a function of time. This plot shows two slopes distinctly. This typical plot is given in Plate X which explains the mixture of two components of 192 Kev gamma ray. Where one component is long lived and the other is short lived.

The long-lived component is extrapolated to zero time. Then the extrapolated count rate of long-lived 192 Kev gamma ray component is subtracted from the total count rate at any given time. The remainder (count rate) is replotted as another line, the slope of which gives the half life of the short-lived 192 Kev gamma ray component.

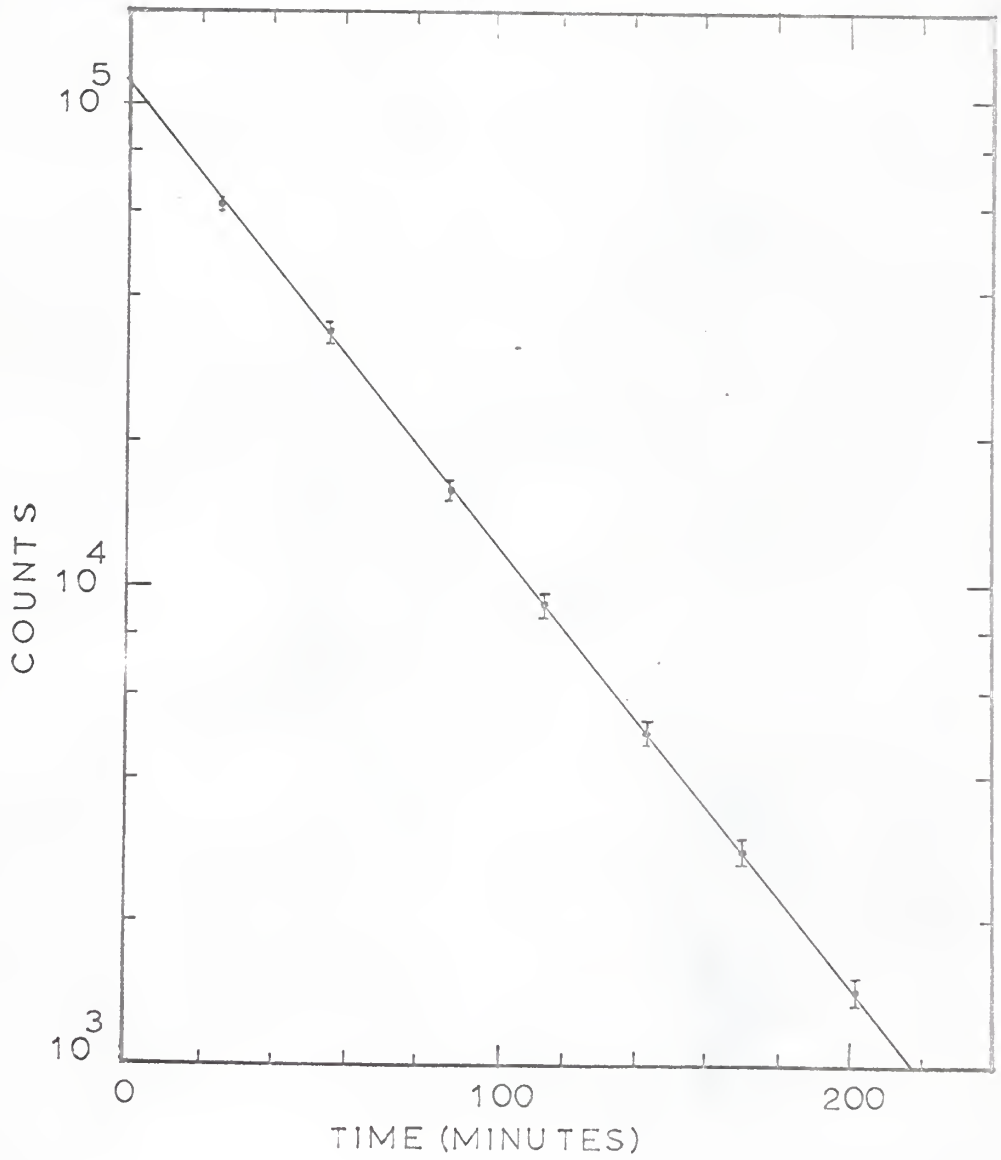
From the slope of these two lines 30 minute and 18 hours, short and long-lived half-lives are found for the two components of 192 Kev gamma ray respectively. The 30 minute component is in the decay of Pt^{199} and 18 hour component is identified as the well known gamma ray in the beta decay of Pt^{197}.

By the analysis of half-life determination of 192 Kev gamma ray, it was possible to separate the 30-minute Pt^{199} gamma ray count rate. So in finding the intensity of 30-minute 192 Kev gamma ray the separated counts were used, which gives the pure intensity of 30-minute 192 Kev gamma ray.

EXPLANATION OF PLATE IX

Decay of 543-keV gamma ray. The line is the least squares fit.

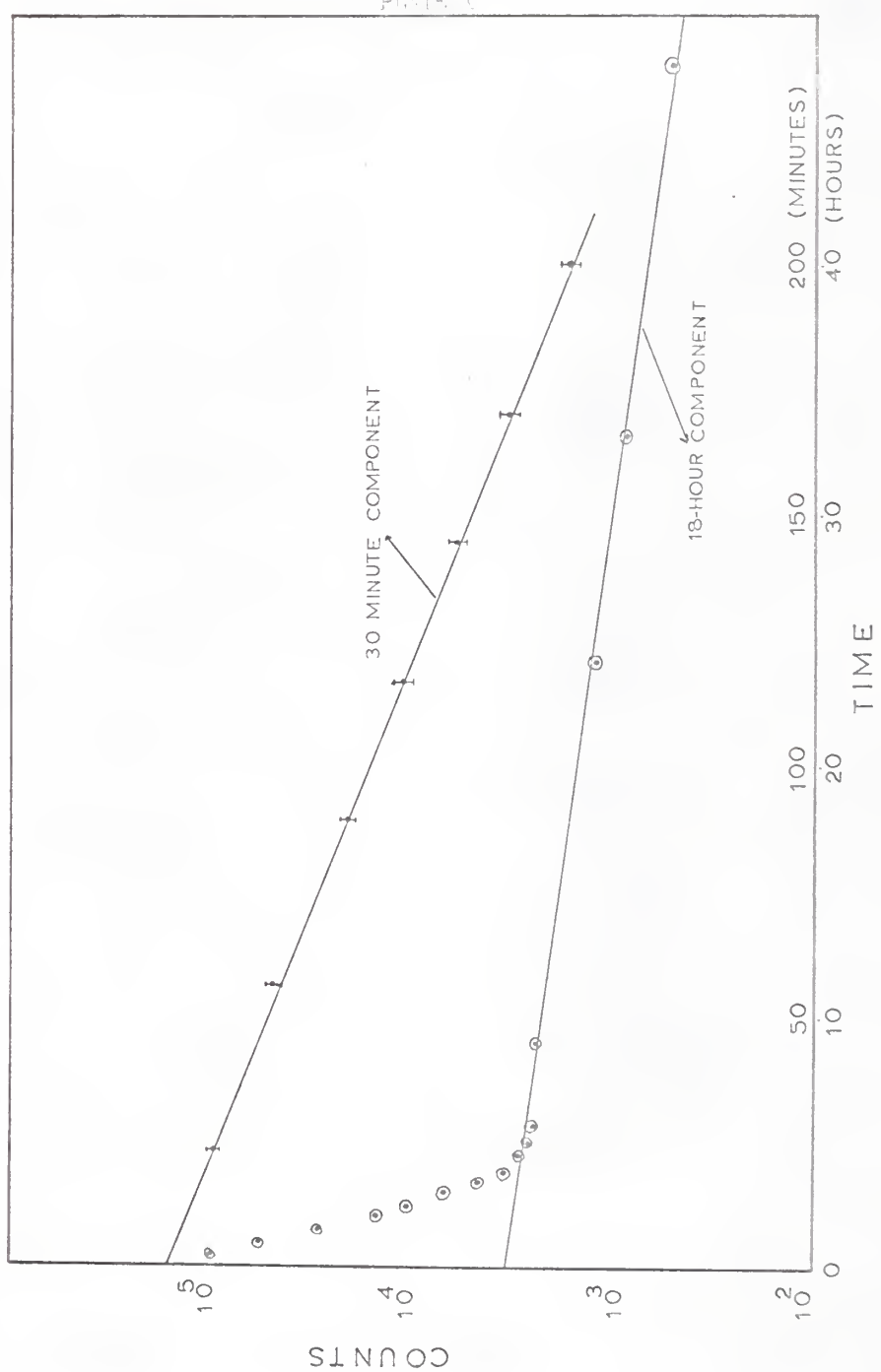
PLATE IX



EXPLANATION OF PLATE X

The curve shows the data of short and long lived components of the 192-keV gamma ray. The long-lived 18-hour component, which has been shown, was subtracted from the original data to find the half-life of the short lived component. This has been replotted in minutes (upper line), giving a 30 minute half-life for the 192-keV gamma ray.

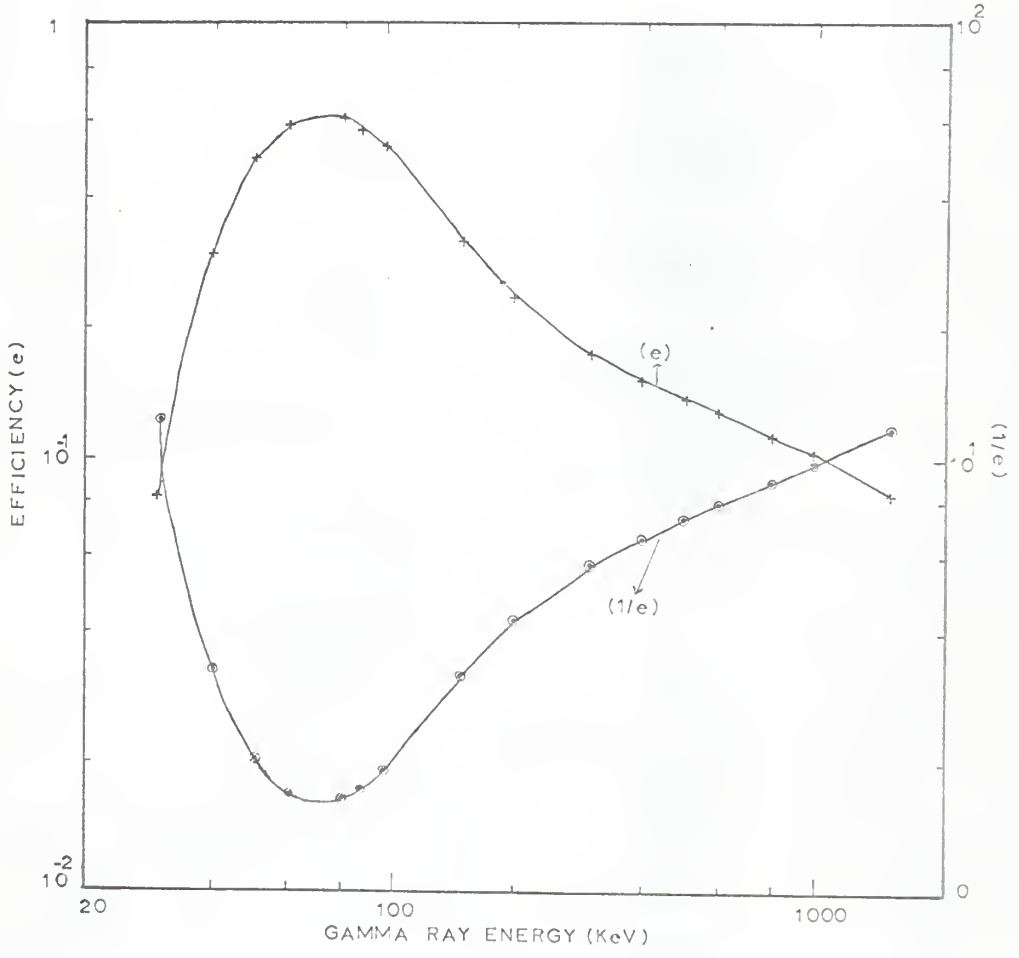
PLATE X


COUNTS
10^5
10^4
10^3
10^2
0
50
100
150
200 (MINUTES)
10
20
30
40 (HOURS)
TIME
30 MINUTE COMPONENT
18-HOUR COMPONENT

EXPLANATION OF PLATE XI

The Detection efficiency "e" and the correction factor which is "1/e" is plotted as a function of gamma-ray energy.

PLATE XI


1
10^{-1}
10^{-2}
EFFICIENCY (e)
10^{2}
10^{1}
0
(1/e)
(e)
(1/e)
20
100
1000
GAMMA RAY ENERGY (KeV)

Determination of Relative Intensities:

The full energy peaks in a given spectrum are used to determine the relative intensities of gamma rays. However, because of the scattering distribution in a spectrum, the total number of gamma rays entering into the detector should be corrected for peak to total ratio and the detector efficiency.

The peak-to-total ratio is defined as the fraction of the total number of events in the pulse-height spectrum which appear in the full-energy peak. The experimental measurement of the full energy peak to total ratio and the calculation of the detector efficiency were necessary for the determination of relative gamma-ray intensities.

These peak-to-total ratios for two different detectors have been measured for SSR detector by Agin (10) and for Isotopes detector by Chao (11), respectively.

The areas under the full energy peaks were obtained from the differentials pulse height distribution of gamma rays in the decay of Pt^{199} by summing the counts per channel over the peak areas, and subtracting an estimated Compton background. Then for several sets of different data for each gamma ray a least-squares fit is plotted as the ln of counting rate vs time from which the uncorrected counts were obtained from half life plot. These quantities are then called, "Uncorrected counts" - Y (0). The corrected counts were then obtained by multiplying the uncorrected counts by appropriate correction factors for detection efficiency and peak-to-total ratio. The total correction factor is the product of the reciprocals of the detection efficiency (e) and the peak-to-total ratio, (P/T) respectively. The corrected counts were normalized to the 543 keV gamma ray which is the most intense one, and by definition called, 100 in intensity. Then the other gamma rays

were compared for intensity with respect to 543 keV, which is 100 in intensity.

The 77-keV gamma ray, which was mixed with K_β X-rays of Pt^{199} and Au^{199} was first corrected for 3.2 days Au^{199} activity. Then these corrected counts were used to find the ratio of K_β and K_α of Pt^{199}. Using the experimentally measured (12) values of K_β/K_α ratio, the actual counts in 77 keV gamma ray were found. The details of separation of 77 keV gamma ray counts from K_β X-ray is given in the Appendix. These separated counts from K_β were used to find the relative intensity of 77 keV gamma ray.

Several gamma ray spectra like the ones shown in Plates V and VI and VIII were used to calculate the gamma ray relative intensities of Pt^{199} decay. Tables 5. and 6. show uncorrected counts, and the corrections used to determine Pt^{199} gamma ray intensities, using two different detectors.

Comparison of the relative intensities determined in this experiment with previously measured intensities is shown in Table 8.

RESULTS AND DISCUSSION

The eleven new gamma rays reported by Black (6) were not all observed in the present investigation of the beta decay of Pt^{199}. In addition, two new gamma rays were observed, which were not reported earlier.

In this experiment 4 to 8 half-lives were followed for each gamma ray. Each one of those which is given in Table 8. has a 31 minute half-life with maximum 3 per cent error. But in the case of 192-keV gamma ray, which was a mixture of long lived and short lived components, investigation for half-life data accumulation was carried out above two days (48 hours). After plotting the counts as a function of time, it became apparent that the 192-keV gamma ray consists of two components, one belonging to beta decay of Pt^{199} of 30-minute half life and another to Pt^{197} of 18-hour half life. The percentage of 18 hour component was 2.7 of the 30 minute activity at the time the sample came out of the reactor. The 192-keV gamma ray was missed by Black (6), due to neglect in following the half life.

Out of the eleven new gamma rays reported by Black (6) the two 836 and 889 keV were not observed presently. If they were present, the intensities reported by Black (6) in Table 1. were 1.4 and 2.1 for 836 and 889 keV gamma rays, respectively, were too large. The upper limits on the relative intensities of 841 and 894 keV gamma rays from the present work are 0.42 and 0.16, respectively.

The 186 keV gamma ray was reported by Black (6) and 197 keV gamma ray was reported by Joshi (3,5) were both observed in the present investigation. The relative intensity of 186 keV gamma ray given by Black (6) was larger than presently observed. The energy given by Joshi (3,5) 197 keV and relative intensity were not correct. The accurate values of energy and relative

Table 5.

The uncorrected counts and the correction factors used to determine Pt^{199} gamma ray relative intensities, using Isotopes detector.

Gamma-ray Energy (keV)	Uncorrected Counts in Thousands	Peak-to-Total Ratio (P/T)	Efficiency (e)	Relative Intensities
Low energy				
77		0.88	0.625	9.3 ± 0.8
186	24.7	0.27	0.288	27.1 ± 0.9
192	131.200	0.36	0.284	14.9 ± 0.9
219	2.26	0.282	0.256	2.44 ± 0.06
226	0.61	0.27	0.254	0.97 ± 0.04
246	6.3	0.234	0.236	13.2 ± 0.6
317	8.9	0.15	0.204	34 ± 1
High energy				
186 + 192	80.0	0.365	0.286	43 ± 1
219 + 226	3.2	0.282	0.256	3.3 ± 0.2
246 + 240	17.5	0.234	0.238	17.8 ± 0.7
317	18.3	0.15	0.204	34 ± 1
418	0.7	0.094	0.179	2.4 ± 0.1
426	0.34	0.091	0.176	1.2 ± 0.2
467	3.49	0.079	0.170	14.8 ± 0.5
475	1.52	0.077	0.168	7.7 ± 0.3
494	9.3	0.073	0.167	43 ± 2
543	17.8	0.064	0.158	100
715	1.41	0.0455	0.140	12.5 ± 0.7
792	0.52	0.0405	0.136	5.3 ± 0.1
968	0.39	0.0323	0.125	5.5 ± 0.3

Table 6.

The uncorrected counts and the correction factors used to determine Pt199 gamma ray relative intensities, using SSR detector.

Gamma-ray Energy (keV)	Uncorrected Counts in Thousands	Peak-to-Total Ratio (P/T)	Efficiency (e)	Relative Intensities
Low energy				
77		0.89	0.604	9.1 ± 0.7
186	198.0	0.43	0.251	25.2 ± 0.6
192	99.0	0.42	0.246	13.2 ± 0.6
219	22.0	0.33	0.220	4.2 ± 0.2
226	0.77	0.316	0.215	0.16 ± 0.04
240	10.0	0.289	0.207	2.3 ± 0.1
246	55.0	0.27	0.202	13.9 ± 0.4
High energy				
186	385.0	0.43	0.251	25.2 ± 0.6
192	169.0	0.42	0.246	11.6 ± 0.5
219	23.0	0.33	0.22	2.2 ± 0.1
226	9.08	0.316	0.215	0.95 ± 0.02
246 + 240	140.0	0.27	0.2	18.2 ± 0.4
317	121.0	0.16	0.17	31.5 ± 0.8
418	4.36	0.094	0.15	2.19 ± 0.06
426	2.08	0.09	0.148	1.1 ± 0.05
467	21.8	0.077	0.142	14.1 ± 0.4
475	10.3	0.073	0.141	7.1 ± 0.3
494	53.0	0.0688	0.1395	39 ± 1
513	109.0	0.0573	0.1345	100
645	0.65	0.044	0.125	0.84 ± 0.03
663	0.26	0.0418	0.123	0.36 ± 0.03
715	8.7	0.037	0.1175	14.1 ± 0.7
792	3.6	0.0317	0.1135	7.1 ± 0.3
968	2.5	0.0248	0.104	6.9 ± 0.3

Table 7.

Relative intensities of gamma rays in the beta decay of Pt^{199}. Gamma ray energies are in keV. Relative intensities are given in parentheses.

Reference 6	Present Work
55 (no photons)	
75	77 (9.2 ± 0.4)
186 (40.1)	186 (25.6 ± 0.8)
	192 (12.5 ± 0.7)
219 (2.2)	219 (2.7 ± 0.6)
226 (3.2)	226 (0.94 ± 0.06)
	240 (2.3 ± 0.1)
246 (16.3)	246 (13.7 ± 0.3)
317 (35.8)	317 (33 ± 1)
417 (1.4)	418 (2.3 ± 0.1)
425 (2.3)	426 (1.11 ± 0.07)
467 (12.6)	467 (14.4 ± 0.4)
474 (9.9)	475 (6.8 ± 0.3)
494 (38.0)	494 (40 ± 2)
543 (100.0)	543 (100)
644 (0.6)	645 (0.34 ± 0.03)
665 (1.2)	663 (0.36 ± 0.03)
715 (12.2)	715 (13.4 ± 0.2)
791 (7.6)	792 (5.6 ± 0.7)
836 (1.4)	841 (0.42)
889 (2.1)	894 (0.16)
967 (6.3)	968 (6.3 ± 0.7)

intensities were assigned to those two gamma rays, which were not found together by either Black (6) or by Joshi (3,5). In the present work the assigned energies and relative intensities were 186 and 192 keV and 25.6 ± 0.8 and 12.5 ± 0.7, respectively. In addition to Black's (6) new eleven gamma rays, the two new ones 192 and 240 keV gamma rays were found in the present investigation. The relative intensities reported by Black for the pairs 219 and 226, 418 and 425, 645 and 663, 841 and 894 keV gamma rays were not correct.

Similarly in other two cases 186 and 246 keV gamma rays, the relative intensities reported by Black (6) were either wrong or he had given combined relative intensities of 186 and 192 and 240 and 246 keV gamma rays, which he could not resolve perhaps due to poor resolution (the resolution was not quoted by him). But in the present work, these pairs are resolved and relative intensities have been found for each gamma ray separately, which were not reported earlier.

The 77 keV gamma ray relative intensity was found in the present investigation, which was not reported earlier, by Black (6) and Joshi (3,5). This gamma ray was mixed with K_β X-rays of gold.

The procedure to separate the gamma ray intensities from that of K X-rays is given in the Appendix.

APPENDIX

Separation of gamma ray intensity from X-ray:

Whenever a gamma ray was mixed with an X-ray, either with K_β or with K_α, to find the intensity of gamma ray first one had to find the number of counts under the X-ray peaks and correct it for background. Then correction was made for the uncorrected counts with peak-to-total ratio and detection efficiency. This gives the corrected counts in the two X-ray peaks.

In the case of Pt^{199} decay, 77 keV gamma ray was mixed with K_β X-ray: so following the above procedure the corrected counts were found for K_α and K_β + 77 keV. Then using the formula given below, from the reference (12)

$$K_\beta/K_\alpha = (K_{\beta_1'}/K_{\alpha_1} + K_{\beta_2'}/K_{\alpha_1}) \frac{1}{1 + K_{\alpha_2}/K_{\alpha_1}} \qquad (1)$$

The different ratios for Pt^{199} to Au^{199} decay were found from reference (12).

$$K_{\alpha_2}/K_{\alpha_1} = 0.5485$$
$$K_{\beta_1'}/K_{\alpha_1} = 0.3465$$
$$K_{\beta_2'}/K_{\alpha_1} = 0.0930$$

using these ratios in equation (1), $K_\beta/K_\alpha = f$ was found. This ratio, $K_\beta = fK_\alpha$ was used to find the actual corrected counts in K_β alone. Then subtracting these corrected counts of K_β from K_β + 77 keV, the corrected counts in 77 keV gamma ray were found. These counts were used to find the relative intensity of 77 keV gamma ray.

In this case the relative intensity for 77 keV gamma ray was found to be 9.2 ± 0.4.

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RELATIVE INTENSITIES OF GAMMA RAYS IN BETA DECAY OF Pt^{199}

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The relative intensities of gamma rays in beta decay of Pt^{199} were studied using lithium-drifted germanium detectors. The radioactive Pt^{199} was produced by the slow neutron capture in platinum metal which was isotopically enriched in Pt^{198} to an extent of 44.36 atomic per cent.

Quantities of two milligrams of platinum metal in the powder form was packed in aluminum foils and were irradiated for thirty minutes in the Triga Mark II reactor at the Kansas State University.

In all nineteen gamma rays were found to have a half-life of thirty minutes and were assigned to the beta decay of Pt^{199}. The energies of these gamma rays are 77, 186, 192, 219, 226, 240, 246, 317, 418, 426, 467, 475, 492, 543, 645, 663, 715, 792, and 968 keV. Their photon intensities relative to 541 keV gamma (taken to be 100) ray are 7.3, 25.6, 12.5, 2.7, 0.94, 2.3, 13.7, 33, 2.3, 1.11, 44.4, 6.8, 40, 100, 0.84, 0.36, 13.4, 5.6, and 6.3.

Two new gamma rays of energies 192 and 240 keV were found and their relative intensities were determined accurately. No strong evidence was found for the 841 and 894 keV gamma rays which were reported earlier. If they are indeed present, the reported intensities are found to be incorrect. The upper limits for their relative intensities are found to be 0.42 and 0.16, respectively.

In this investigation, the relative intensity of 77 keV gamma ray which was mixed with K X-rays of gold was determined for the first time. This was possible due to the good resolution of the Ge(Li) detectors.

These new results indicate that the presently known decay scheme of Pt^{199} is not entirely correct and needs a thorough investigation.