

# SYSTEMATICS OF MAGNETIC DIPOLE TRANSITIONS

BY A. S. VENKATESHA MURTHY AND M. K. RAMASWAMY, F.A.Sc

(Department of Physics, Karnatak University, Dharwar-3)

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## ABSTRACT

An empirical approach to distinguish between  $l$ -allowed and  $l$ -forbidden magnetic dipole transitions is made. The reduced lifetimes of these transitions are calculated and their variation with neutron number is studied. It is observed that their general tendency is to remain constant while  $l$ -forbidden and  $l$ -allowed odd-proton magnetic dipole transitions are distinguishable from their reduced lifetimes, it is not so in the case of odd-neutron transitions. A slight increase in reduced lifetime with neutron number is observed for fixed proton number.

## INTRODUCTION

THE remarkable success of the single particle shell model in accounting for angular momenta and parities of low lying states of odd- $A$  nuclei has extended its applicability in many cases. Experimentally the spins and parities of excited states can be determined from a knowledge of the type (Electric or Magnetic) and multipolarity of the radiation, which are known by measuring internal conversion coefficient, without any detailed knowledge of the wave functions of initial and final states. Comparison of experimentally determined gamma transition probabilities with the ones calculated on the basis of some specific assumptions yields valuable information on the wave functions of the initial and final states. Various authors have compared the electromagnetic transition rates with the single particle estimate, to know how far the shell model of nuclear structure is able to explain the properties of excited states. But it has not been possible to obtain qualitative agreement in the case of  $l$ -forbidden magnetic dipole transitions. Since the dipole moment operator does not change the orbital angular momentum, the initial and final state angular momentum should be the same for magnetic dipole transition. Those transitions which do not obey this shell model rule are called  $l$ -forbidden transitions,

There have been many<sup>1-4</sup> attempts to explain the behaviour of *l*-forbidden transitions using modified shell structure. Among these the one<sup>4</sup> based on the assumption that *l*-forbidden transitions occur owing to the admixture of other configurations in the initial or final states of the radiating particle is somewhat fruitful. Recently, Sorenson<sup>5</sup> has discussed the effect of quadrupole vibrations on *l*-forbidden M1 transition and finds that even for non-deformed nuclei that collective quadrupole effects are important. But the fastness of *l*-forbidden M1 rates for odd-N nuclei cannot be explained. The compilation of experimental data by Way *et al.*,<sup>6</sup> gives the average value of the ratio of observed lifetime of the forbidden transitions to the theoretical value of allowed transitions, as 60 for odd-neutron nuclei and 300 for odd-proton nuclei. Earlier, De waard<sup>3</sup> reported marked regularities in the short-lived isomeric transitions of the *l*-forbidden magnetic dipole transitions. It was noticed that these transitions give points in a log energy ( $E_\gamma$ ) versus lifetime,  $\tau_\gamma$  plot that are closely grouped along two straight lines, the line given by  $\log \tau l = -10.0 - 3 \log E_\gamma$  closely matches transitions in odd-proton nuclei, the one given by  $\log \tau = -11.7 - 3 \log E$  those in odd-neutron nuclei. Alvager<sup>7</sup> observed that  $\log(\tau E_\gamma^3)$  is almost constant for *l*-forbidden transitions of the type  $d_{3/2} \leftrightarrow S_{1/2}$  and also pointed out the tendency of the value of reduced lifetime to increase with neutron number for fixed proton number.

In recent years there have been many investigations on the properties of low excited state, the gamma transitions of which are found to be *l*-forbidden. The purpose of the present paper is to compile the data available on *l*-forbidden as well as *l*-allowed transitions and to observe the trend in the values of reduced lifetimes with neutron number and arrive at some sort of systematics, from which one can possibly distinguish between *l*-allowed and *l*-forbidden M1 transitions without any precise knowledge of the orbital angular momentum of the states involved in transition:

#### ANALYSIS OF DATA AND RESULTS

Data on *l*-forbidden and *l*-allowed transitions are taken from recent publications references for which are given in Tables I to VI. The *l*-forbidden transitions are classified according to the type of transition, such as  $d_{3/2} \leftrightarrow S_{1/2}$ ,  $f_{5/2} \leftrightarrow P_{3/2}$  and  $g_{7/2} \leftrightarrow d_{5/2}$ . But in the case of *l*-allowed transitions, as the number of cases in each type of transition is small, all types of transitions are taken together. In each case a graph of  $\log_{10}(\tau_\gamma E_\gamma^3)$  versus  $N$ , the neutron number is plotted.  $E_\gamma$  is the energy in Mev, and  $\tau$  is given by

$$\tau (M1) = 1.44 (1 + a_t) (1 + E 2/M1) T_{1/2}$$

TABLE I

 $\tau E_r^3$  for odd-neutron 1-forbidden M1 transitions of the type  $d_{3/2} \leftrightarrow S_{1/2}$ 

Nucleus	$E_r$ (Kev.)	Transition	$\tau$ (MI)	$\tau E_r^3$	$\log (\tau E_r^3)$	Reference
$_{48}\text{Cd}_{36}^{111}$	340	$3/2^+ \rightarrow 1/2^+$	$2.28 \times 10^{-11}$	$8.98 \times 10^{-13}$	$\bar{13}.9$	1
$_{48}\text{Cd}_{65}^{113}$	300	$3/2^+ \rightarrow 1/2^+$	$5.15 \times 10^{-11}$	$1.39 \times 10^{-12}$	$\bar{12}.14$	1
$_{50}\text{Sn}_{69}^{119}$	24	$3/2^+ \rightarrow 1/2^+$	$1.89 \times 10^{-7}$	$2.61 \times 10^{-12}$	$\bar{12}.41$	2
$_{52}\text{Te}_{69}^{121}$	214	$3/2^+ \rightarrow 1/2^+$	$3.26 \times 10^{-9}$	$3.19 \times 10^{-11}$	$\bar{11}.50$	2
$_{52}\text{Te}_{71}^{123}$	159	$3/2^+ \rightarrow 1/2^+$	$3.3 \times 10^{-10}$	$1.32 \times 10^{-12}$	$\bar{12}.1$	3
$_{52}\text{Te}_{73}^{125}$	35	$3/2^+ \rightarrow 1/2^+$	$4.4 \times 10^{-8}$	$1.87 \times 10^{-12}$	$\bar{12}.27$	3
$_{54}\text{Xe}_{75}^{129}$	40	$3/2^+ \rightarrow 1/2^+$	$1.25 \times 10^{-8}$	$8.0 \times 10^{-13}$	$\bar{13}.9$	1, 2
$_{54}\text{Xe}_{77}^{131}$	80	$3/2^+ \rightarrow 1/2^+$	$1.87 \times 10^{-9}$	$9.62 \times 10^{-13}$	$\bar{13}.98$	2
$_{56}\text{Ba}_{77}^{133}$	11.7	$3/2^+ \rightarrow 1/2^+$	$3.3 \times 10^{-7}$	$5.28 \times 10^{-13}$	$\bar{13}.72$	4

TABLE II

 $\tau E_r^3$  for odd-proton 1-forbidden M1 transitions of the type  $d_{3/2} \leftrightarrow S_{1/2}$ 

Nucleus	$E_r$ (Kev.)	Transition	$\tau$ (MI)	$\tau E_r^3$	$\log (\tau E_r^3)$	Reference
$_{79}\text{Au}_{114}^{192}$	38	$1/2^+ \rightarrow 3/2^+$	$6.99 \times 10^{-7}$	$3.83 \times 10^{-11}$	$\bar{11}.5$	5
$_{79}\text{Au}_{116}^{195}$	65	$1/2^+ \rightarrow 3/2^+$	$6.66 \times 10^{-8}$	$1.83 \times 10^{-11}$	$\bar{11}.26$	5
$_{79}\text{Au}_{118}^{197}$	77	$1/2^+ \rightarrow 3/2^+$	$1.21 \times 10^{-8}$	$5.55 \times 10^{-12}$	$\bar{12}.74$	5
$_{81}\text{Tl}_{120}^{201}$	330	$3/2^+ \rightarrow 1/2^+$	$1.60 \times 10^{-10}$	$6.00 \times 10^{-10}$	$\bar{12}.78$	6
$_{81}\text{Tl}_{122}^{203}$	279	$3/2^+ \rightarrow 1/2^+$	$2.29 \times 10^{-12}$	$4.97 \times 10^{-14}$	$\bar{14}.69$	7
$_{81}\text{Tl}_{124}^{205}$	205	$3/2^+ \rightarrow 1/2^+$	$9.66 \times 10^{-9}$	$8.32 \times 10^{-11}$	$\bar{11}.9$	7

TABLE III

 $\tau E_{\tau}^3$  for odd-proton 1-forbidden M1 transitions of the type  $f_{5/2} \leftrightarrow P_{3/2}$ 

Nucleus	$E_{\tau}$ (Kev.)	Transition	$\tau$ (Ml)	$\tau E_{\tau}^3$	$\log(\tau E_{\tau}^3)$	Reference
${}_{23}\text{V}_{28}^{51}$	610	$3/2^- \rightarrow 5/2^-$	$3.12 \times 10^{-11}$	$7.09 \times 10^{-12}$	$\bar{1}2.85$	8
${}_{29}\text{Cu}_{34}^{63}$	963	$5/2^- \rightarrow 3/2^-$	$8.4 \times 10^{-13}$	$7.5 \times 10^{-13}$	$\bar{1}3.87$	9
${}_{29}\text{Cu}_{36}^{65}$	1114	$5/2^- \rightarrow 3/2^-$	$11.9 \times 10^{-13}$	$1.64 \times 10^{-12}$	$\bar{1}2.21$	10
${}_{33}\text{As}_{42}^{75}$	280	$5/2^- \rightarrow 3/2^-$	$5.61 \times 10^{-10}$	$1.23 \times 10^{-11}$	$\bar{1}1.09$	11
${}_{47}\text{As}_{60}^{107}$	99	$5/2^- \rightarrow 3/2^-$	$7.20 \times 10^{-10}$	$6.99 \times 10^{-13}$	$\bar{1}3.84$	7, 12
${}_{47}\text{As}_{62}^{109}$	109	$5/2^- \rightarrow 3/2^-$	$9.38 \times 10^{-10}$	$1.15 \times 10^{-12}$	$\bar{1}2.06$	7, 12

TABLE IV

 $\tau E_{\tau}^3$  for odd-proton 1-forbidden M1 transitions of the type  $g_{7/2} \leftrightarrow d_{5/2}$ 

Nucleus	$E_{\tau}$ (Kev.)	Transition	$\tau$ (Ml)	$\tau E_{\tau}^3$	$\log(\tau E_{\tau}^3)$	Reference
${}_{51}\text{Sb}_{70}^{121}$	70	$7/2^+ \rightarrow 5/2^+$	$2.98 \times 10^{-8}$	$1.02 \times 10^{-11}$	$\bar{1}1.01$	13
${}_{51}\text{Sb}_{70}^{121}$	37	$7/2^+ \rightarrow 5/2^+$	$6.00 \times 10^{-8}$	$3.04 \times 10^{-12}$	$\bar{1}2.48$	14
${}_{55}\text{Cs}_{76}^{131}$	123.7	$5/2^+ \rightarrow 7/2^+$	$1.02 \times 10^{-7}$	$1.93 \times 10^{-10}$	$\bar{1}0.28$	15
${}_{55}\text{Cs}_{78}^{133}$	81	$5/2^+ \rightarrow 7/2^+$	$2.48 \times 10^{-8}$	$1.32 \times 10^{-11}$	$\bar{1}1.12$	16
${}_{55}\text{Cs}_{80}^{135}$	248	$5/2^+ \rightarrow 7/2^+$	$4.4 \times 10^{-10}$	$6.26 \times 10^{-12}$	$\bar{1}2.79$	4
${}_{57}\text{La}_{80}^{137}$	10	$5/2^+ \rightarrow 7/2^+$	$1.67 \times 10^{-7}$	$1.67 \times 10^{-13}$	$\bar{1}3.22$	17
${}_{57}\text{La}_{82}^{139}$	166	$5/2^+ \rightarrow 7/2^+$	$2.6 \times 10^{-9}$	$1.19 \times 10^{-11}$	$\bar{1}1.07$	18
${}_{59}\text{Pr}_{82}^{141}$	145	$7/2^+ \rightarrow 5/2^+$	$4.2 \times 10^{-9}$	$1.28 \times 10^{-11}$	$\bar{1}1.1$	18, 23
${}_{59}\text{Pr}_{84}^{143}$	57	$7/2^+ \rightarrow 5/2^+$	$5.4 \times 10^{-8}$	$1.00 \times 10^{-11}$	$\bar{1}1.0$	18
${}_{61}\text{Pm}_{84}^{145}$	61	$7/2^+ \rightarrow 5/2^+$	$2.9 \times 10^{-8}$	$6.58 \times 10^{-12}$	$\bar{1}2.8$	18
${}_{61}\text{Pm}_{86}^{147}$	91	$5/2^+ \rightarrow 7/2^+$	$1.12 \times 10^{-8}$	$8.43 \times 10^{-12}$	$\bar{1}2.92$	18, 21
${}_{63}\text{Eu}_{84}^{147}$	229	$7/2^+ \rightarrow 5/2^+$	$3.2 \times 10^{-10}$	$3.84 \times 10^{-12}$	$\bar{1}2.57$	18
${}_{63}\text{Eu}_{86}^{149}$	160	$7/2^+ \rightarrow 5/2^+$	$7.5 \times 10^{-10}$	$3.07 \times 10^{-12}$	$\bar{1}2.45$	18
${}_{63}\text{Eu}_{88}^{151}$	21	$7/2^+ \rightarrow 5/2^+$	$1.47 \times 10^{-7}$	$1.36 \times 10^{-12}$	$\bar{1}2.1$	18, 22

TABLE V  
 $\tau E_{\tau}^3$  for odd-neutron 1-allowed *MI* transitions

Nucleus	$E_{\tau}$ (Kev.)	Transition	$\tau$ (MI)	$\tau E_{\tau}^3$	$\log(\tau E_{\tau}^3)$	Reference
${}_{26}\text{Fe}_{31}^{57}$	14	$3/2^- \rightarrow 1/2^-$	$1.73 \times 10^{-6}$	$5.18 \times 10^{-12}$	$\bar{12}.71$	19
${}_{34}\text{Se}_{43}^{77}$	246	$1/2^- \rightarrow 3/2^-$	$1.1 \times 10^{-10}$	$1.63 \times 10^{-12}$	$\bar{12}.21$	20
${}_{36}\text{Kr}_{47}^{83}$	9.3	$7/2^+ \rightarrow 9/2^+$	$2.48 \times 10^{-7}$	$2.1 \times 10^{-12}$	$\bar{12}.3$	17
${}_{42}\text{Mo}_{53}^{95}$	203	$5/2^+ \rightarrow 3/2^+$	$1.46 \times 10^{-9}$	$1.21 \times 10^{-11}$	$\bar{11}.08$	20
${}_{48}\text{Cd}_{63}^{111}$	95	$3/2^+ \rightarrow 5/2^+$	$6.49 \times 10^{-11}$	$5.56 \times 10^{-13}$	$\bar{13}.74$	1
${}_{48}\text{Cd}_{65}^{113}$	282	$3/2^+ \rightarrow 5/2^+$	$6.89 \times 10^{-10}$	$1.54 \times 10^{-11}$	$\bar{11}.18$	1
${}_{54}\text{Xe}_{77}^{131}$	284	$5/2^+ \rightarrow 3/2^+$	$3.21 \times 10^{-11}$	$7.36 \times 10^{-13}$	$\bar{13}.86$	2
${}_{80}\text{Hg}_{119}^{199}$	208 ]	$3/2^- \rightarrow 1/2^-$	$2.24 \times 10^{-10}$	$2.02 \times 10^{-12}$	$\bar{12}.30$	7

TABLE VI  
 $\tau E_{\tau}^3$  for odd-proton 1-allowed *MI* transitions

Nucleus	$E_{\tau}$ (Kev.)	Transition	$\tau$ (MI)	$\tau E_{\tau}^3$	$\log(\tau E_{\tau}^3)$	Reference
${}_{23}\text{V}_{28}^{51}$	320	$5/2^- \rightarrow 7/2^-$	$3.04 \times 10^{-9}$	$9.95 \times 10^{-11}$	$\bar{11}.99$	8
${}_{25}\text{Mn}_{30}^{55}$	128	$5/2^- \rightarrow 7/2^-$	$3.5 \times 10^{-10}$	$7.34 \times 10^{-13}$	$\bar{13}.86$	20
${}_{29}\text{Cu}_{34}^{63}$	669	$1/2^- \rightarrow 3/2^-$	$3.00 \times 10^{-13}$	$8.98 \times 10^{-14}$	$\bar{14}.95$	9
${}_{47}\text{Ag}_{60}^{107}$	324	$3/2^- \rightarrow 1/2^-$	$1.05 \times 10^{-12}$	$3.57 \times 10^{-14}$	$\bar{14}.55$	7
${}_{47}\text{Ag}_{62}^{109}$	309	$3/2^- \rightarrow 1/2^-$	$8.33 \times 10^{-12}$	$2.46 \times 10^{-13}$	$\bar{13}.39$	7
${}_{51}\text{Sb}_{70}^{121}$	506	$3/2^+ \rightarrow 5/2^+$	$3.0 \times 10^{-12}$	$3.88 \times 10^{-13}$	$\bar{13}.58$	14
${}_{79}\text{Au}_{114}^{193}$	258	$5/2^+ \rightarrow 3/2^+$	$2.34 \times 10^{-7}$	$4.01 \times 10^{-9}$	$\bar{9}.60$	5
${}_{79}\text{Au}_{115}^{197}$	279	$5/2^+ \rightarrow 3/2^+$	$3.51 \times 10^{-11}$	$7.63 \times 10^{-13}$	$\bar{13}.88$	5
${}_{81}\text{Tl}_{123}^{203}$	401	$5/2^+ \rightarrow 3/2^+$	$2.29 \times 10^{-12}$	$1.46 \times 10^{-13}$	$\bar{13}.16$	
${}_{81}\text{Tl}_{124}^{205}$	410	$5/2^+ \rightarrow 3/2^+$	$3.19 \times 10^{-12}$	$2.2 \times 10^{-13}$	$\bar{13}.34$	7

Where  $a_t$  = Total internal conversion coefficient, and  $T_{1/2}$  = Half life of the state in sec. The theoretical line for proton transition given by Moszkowski<sup>8</sup>, is drawn on each graph assuming the statistical factor to be unity. Calculations for nuclei in deformed region are not made as the single particle model is not a good approximation in that region.

## L-FORBIDDEN TRANSITIONS

In Fig. 1 the  $\log(\tau E_\gamma^3)$  values are plotted against neutron number for odd-neutron transitions of the type  $d_{3/2} \leftrightarrow S_{1/2}$ . It can be seen that the values

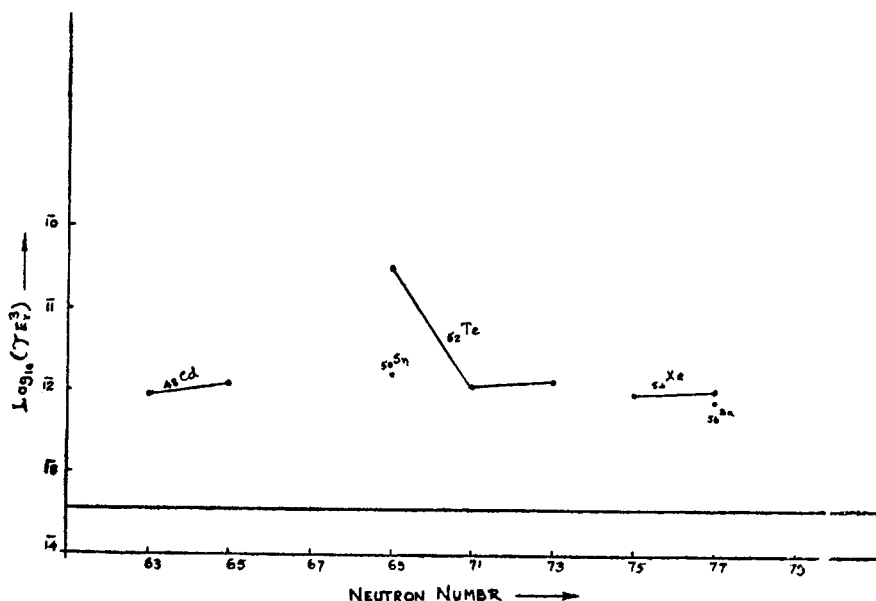


FIG. 1. Variation of  $\log_{10}(\tau E_\gamma^3)$  with neutron number for odd-neutron  $l$ -forbidden M1 transitions of the type  $d_{3/2} \leftrightarrow S_{1/2}$ . Isotopes are connected by lines.

of  $\log(\tau E_\gamma^3)$  are almost constant and lie in the neighbourhood of  $\overline{12}$ .  $\log(\tau E_\gamma^3)$  values show a tendency to increase slightly with neutron number for fixed proton number. Only  $\text{Te}^{121}$  deviates from these conclusions. This may be because of the fact that the upper limit of the lifetime is considered for calculation. Precise determination of the half life of 214 Kev. excited level may bring the value of  $\log(\tau E_\gamma^3)$  near  $\overline{12}$ .

It is unfortunate that data on only a few cases of odd-proton transition of the type  $d_{3/2} \leftrightarrow S_{1/2}$  is available to make any definite conclusions. Within the context of the limited data, it can be remarked that even though  $\log(\tau E_\gamma^3)$  values do not show a tendency to remain constant they are scattered around

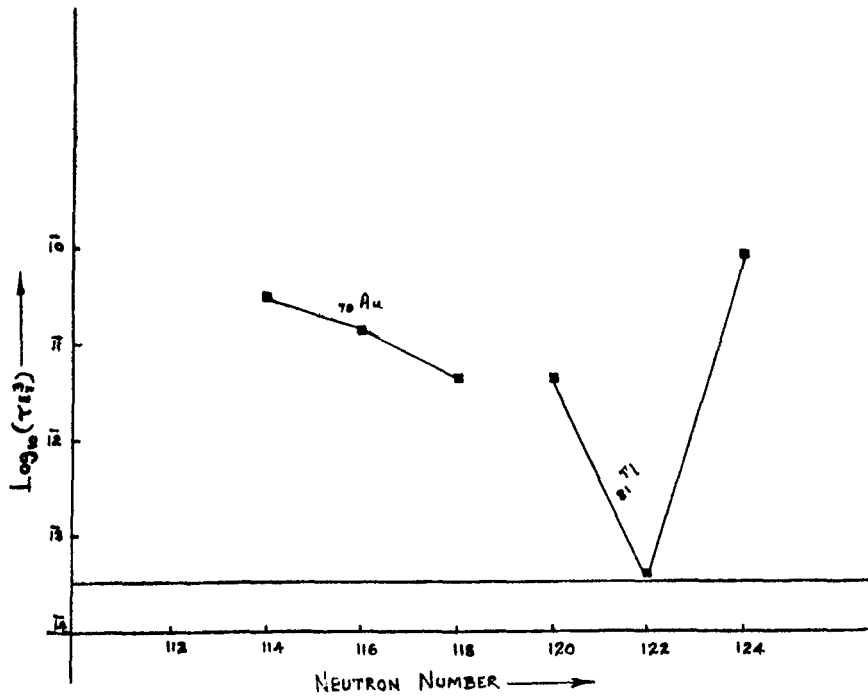


FIG. 2. Variation of  $\log_{10}(\tau E^2)$  with neutron number for odd-proton  $l$ -forbidden M1 transitions of the type  $d_{3/2} \leftrightarrow S_{1/2}$ . Isotopes are connected by lines.

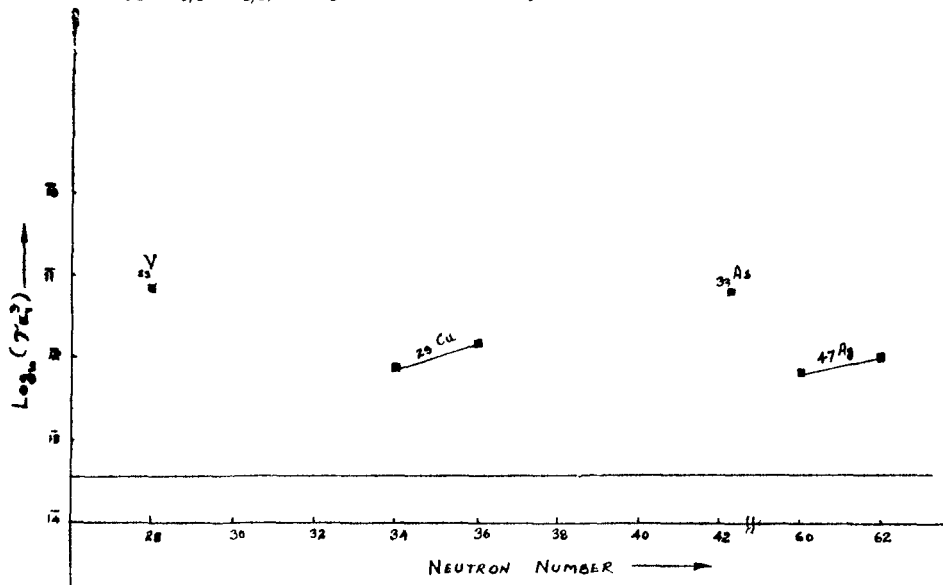


FIG. 3. Variation of  $\log_{10}(\tau E^2)$  with neutron number for odd-proton  $l$ -forbidden M1 transitions of the type  $f_{5/2} \leftrightarrow d_{3/2}$ . Isotopes are connected by lines.

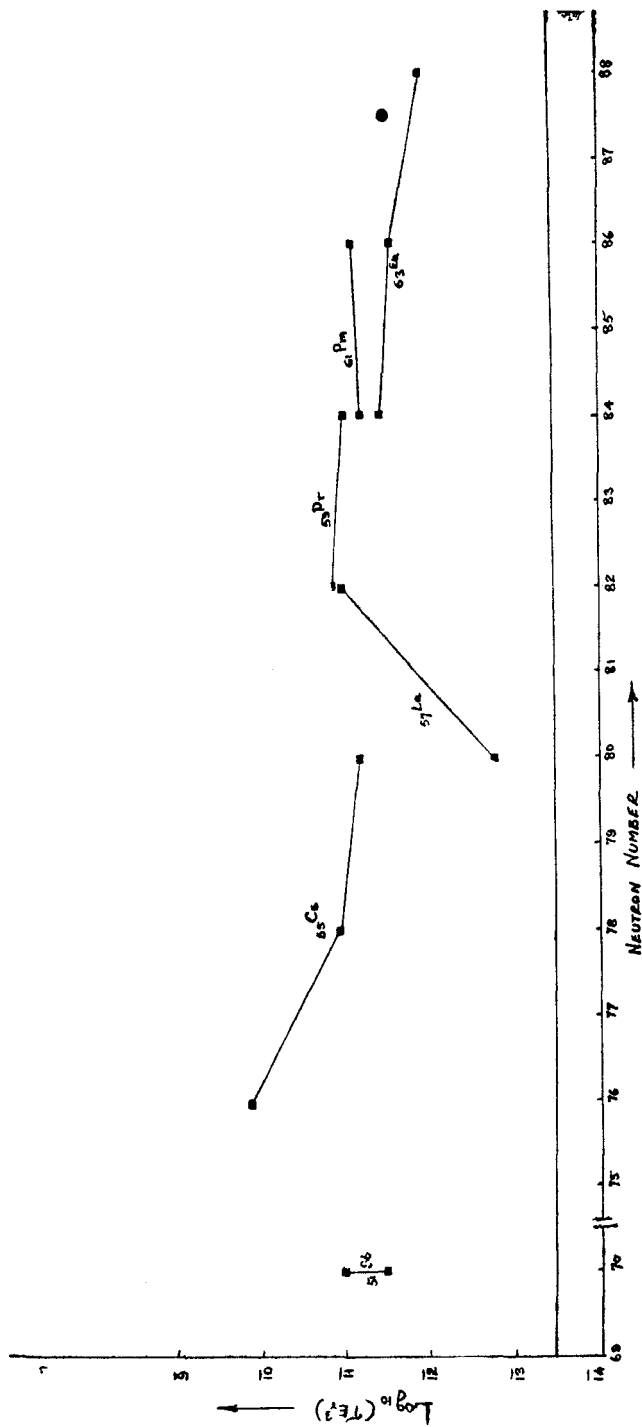


FIG. 4. Variation of  $\log_{10}(\tau E_{\gamma}^2)$  with neutron number for odd-proton  $I$ -forbidden  $M1$  transitions of the type  $g_{7/2} \leftrightarrow d_{5/2}$ . Iso are connected by lines.



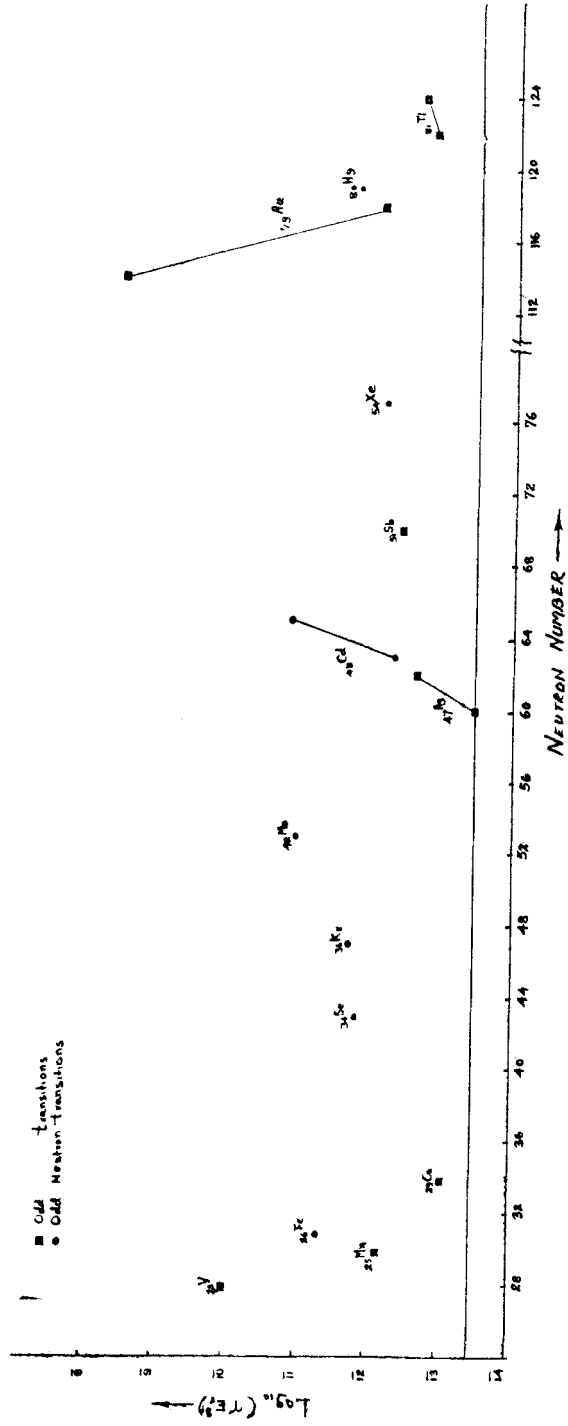


FIG. 5. Variation of  $\log_{10}(\tau/E_{\gamma}^2)$  with neutron number for  $l$ -allowed M1 transitions indicates odd-neutron transitions. Isotopes are connected by lines. ● indicates odd-neutron transitions. □ indicates odd-proton transitions.

$\overline{11}$ . It is interesting to note that  $\log(\tau E_{\gamma}^3)$  values for odd-proton transition are greater than the corresponding odd-neutron transition by a factor of 10. Contradictory to this the odd-neutron  $l$ -allowed M1 transitions are faster than the odd-proton  $l$ -allowed M1 transitions. For Au isotopes,  $\log(\tau E_{\gamma}^3)$  decreases while it increases in the case of Tl isotopes as  $N$  increases.  $Tl^{203}$  is an exception to the above observation and is very close to single particle estimate.

In Table III data on  $l$ -forbidden odd-proton transitions of the type  $f_{5/2} \leftrightarrow P_{3/2}$  are shown. In the case of  $V^{51}$   $\tau$  (M1) is calculated from (1) the reduced transition probability B ( $E2 \ 3/2 \leftrightarrow 7/2$ ), (2) the cascade/crossover ratio for the decay of  $\overline{3/2}$  level and (3) the E2/M1 mixing parameter. It is seen from Fig. 3 that  $\log(\tau E_{\gamma}^3)$  is almost constant and lies in the neighbourhood of  $\overline{12}$ , which means that  $\log(\tau E_{\gamma}^3)$  value is less than that of  $d_{3/2} \leftrightarrow S_{1/2}$  odd-proton transitions and equal to that of the  $d_{3/2} \leftrightarrow S_{1/2}$  odd-neutron transitions.  $V^{51}$  and  $As^{75}$  deviate from this rule. Here again it is observed that for Ag and Cu isotopes  $\log(\tau E_{\gamma}^3)$  increases with neutron number.

Figure 4 shows the variation of  $\log(\tau E_{\gamma}^3)$  with neutron number for odd-proton transitions of the type  $g_{7/2} \leftrightarrow d_{5/2}$ . The reduced lifetime of these transitions is almost constant with a value equal to  $\overline{11}$ . Comparing this with the other types of transition, it is observed that it is equal to the reduced life-time of  $d_{3/2} \leftrightarrow S_{1/2}$  odd-proton transition while it is 10 times larger than that of  $d_{3/2} \leftrightarrow S_{1/2}$  odd neutron and  $f_{5/2} \leftrightarrow P_{3/2}$  odd-proton transitions.  $\log(\tau E_{\gamma}^3)$  value decreases in the isotopes of Cs and Pr while it increases in the isotopes of La and Pm. In the case of  $Eu^{151}$  there exists some discrepancy in the value of lifetime of 21 Kev. excited state reported by several investigators. Taking  $T_{1/2} = 3.4 \times 10^{-9}$  sec. reported by Berlovich *et al.*<sup>9</sup> the value of  $\log(\tau E_{\gamma}^3)$  comes to  $\overline{12.1}$  (shown in Fig. 4). Horen *et al.*<sup>10</sup> give  $T_{1/2} = (9.5 \pm 0.5) \times 10^{-9}$  sec. for the same level, using which gives  $\overline{12.58}$  (not shown in Figure), for  $\log(\tau E_{\gamma}^3)$  which comes nearer to our empirical value of  $\overline{11}$ . Reinvestigation on the lifetime of 21 Kev. level in  $Eu^{151}$  may clarify this situation. La<sup>137</sup> being nearer to and Cs<sup>131</sup> being farther away from the single particle estimate deviate from the above conclusions.

#### L-ALLOWED ML TRANSITIONS

The variation of  $\log(\tau E_{\gamma}^3)$  with neutron number for both odd-proton and odd-neutron transitions are shown in a single plot.  $\log(\tau E_{\gamma}^3)$  values for odd-proton transition are grouped around  $\overline{13.5}$  which is nearly 10 times

larger than the single particle estimate. This speaks of the impurity of the states involved in the transition. The situation is worse in the case of odd-neutron transitions. It is a surprise to find that the  $\log(\tau E_{\gamma}^3)$  value for odd-neutron  $l$ -allowed transitions is somewhat equal to that of  $l$ -forbidden odd-neutron transitions of the type  $d_{3/2} \leftrightarrow S_{1/2}$ . In odd proton transitions,  $V^{51}$  and  ${}^7\text{Au}^{193}$ , and in odd-neutron transitions,  $\text{Cd}^{113}$  are exceptions.

### CONCLUSIONS

The general tendency of  $\log(\tau E_{\gamma}^3)$  value for each type of transition is to remain constant. In the case of  $l$ -forbidden transitions, the value of  $\log(\tau E_{\gamma}^3)$  lies near  $\overline{12}$  for  $d_{3/2} \leftrightarrow S_{1/2}$  odd-neutron transitions and  $f_{5/2} \leftrightarrow P_{3/2}$  odd-proton transitions, and  $\overline{11.0}$  for  $g_{7/2} \leftrightarrow D_{5/2}$  and  $d_{3/2} \leftrightarrow S_{1/2}$ , odd-proton transitions. In the case of  $l$ -allowed odd-proton and odd-neutron transitions the  $\log(\tau E_{\gamma}^3)$  values are respectively  $\overline{13.5}$  and  $\overline{12.0}$ . This shows that it is *not* possible to distinguish between  $l$ -allowed and  $l$ -forbidden odd-neutron transitions unless the orbital angular momenta of the two levels involved in the transitions are known. But, however, it is possible to distinguish between  $l$ -forbidden and  $l$ -allowed odd-proton transition empirically depending on their reduced lifetimes. In each type of transitions discussed above  $\log \leftrightarrow (\tau E_{\gamma}^3)$  value increases slightly except in  $g_{7/2} \leftrightarrow d_{5/2}$  odd-proton  $l$ -forbidden transitions where the value decreases with neutron number for fixed proton number.

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