# CLASSIFICATION OF EXCITED STATES OF EVEN-EVEN NUCLEI

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## Abstract

In this paper we have attempted to see how far a classification of excited states of even-even nuclei can be made based on the quantity AE, A being the mass number and E, the energy of excitation. The results show that this may be a useful criterion in the understanding of the excitation mechanism.

Excited states of even-even nuclei are interesting from the theoretical point of view. Various models have been put forward to give a description of the excited states. The strong coupling collective model is successfully applied to the heavy nuclei and nuclei in the rare-earth region. In the case of medium-weight nuclei configuration mixing in the shell-model, the weak coupling and intermediate coupling models (collective) as also the asymmetric rotor model of Davydov and Filippov have been proposed.

All these models predict a first excited state which is $2^+$. For the second excited state the weak coupling model predicts a triplet of $0^+$, $2^+$ and $4^+$ states, whereas the asymmetric rotor model with beta vibration included predicts similar states, as also the intermediate coupling model. $0^+$ excited states can be either shell model states or result from the beta vibration band. $3^-$ levels have been interpreted as the octupole vibrations of the even-even core. On the basis of the shell model, the configurations which give a $3^-$ state also yield a $5^-$ state. However, the $5^-$ states can be interpreted[1] as belonging to the $\lambda = 5$ mode of collective vibration.

Classification of these excited states on the basis of the excitation energy or energy ratios is usually ambiguous. We have attempted in this paper to see how far the product AE, A being the mass number and E, the excitation energy, can be used as a possible criterion for classifying the excited states. Table I shows this attempt. In column 1 are included those even-even nuclei for which $0^+$, $2^+$, $0^{+\prime}$, $2^{+\prime}$, $3^-$ and $5^-$ levels exist. Columns 2, 4, 6, 8 and 10 give the excitation energies of these states. The $0^{+\prime}$ second excited state is listed just below the first excited $0^{+}$ state; columns 3, 5, 7, 9 and 11 indicate the product AE for the respective states. The last column gives the reference.

The following conclusions are drawn from Table I.

### *A.* $0^{+}$ *First Excited State*

The product AE is sensitive to the shell structure and magic numbers. Whenever we are in the vicinity of a closed shell the product rises to a high value. The value AE lies between 80 and 200 for light and medium-weight nuclei whereas it assumes a value between 180 and 360 for deformed and heavy nuclei.

### *B.* $0^{+\prime}$ *Second Excited State*

The product AE is insensitive to the shell closure. With the exception of Hf-178 the product is almost a constant and lies between 140 and 160. The accumulation of more extensive data may however alter this conclusion. The value is closer to AE ($2^{+\prime}$) than AE ($2^{+}$) in the same nuclei.

### *C.* $2^{+}$ *First Excited and* $2^{+\prime}$ *Second Excited States*

The values of AE are quite sensitive to shell closure and magic numbers. AE has a high value whenever N or Z equals a magic number.

(1) AE ($2^{+}$) lies between 30 and 140 for light and medium-weight nuclei. AE ($2^{+\prime}$) ranges from 100 to 180. Further, the value AE ($2^{+\prime}$) is about twice that of AE ($2^{+}$).

(2) AE ($2^{+}$) lies in a small range of 10 to 40 for deformed and heavy nuclei. But AE ($2^{+\prime}$) does not show any such range. Another point that may be noted in this case is that for heavy nuclei the value of AE ($2^{+}$) remains almost constant (10) whereas the value of AE ($2^{+\prime}$) rises rather high.

### *D.* $3^{-}$ *and* $5^{-}$ *levels*

Ae ($3^{-}$) and AE ($5^{-}$) do not show any sensitiveness to shell closure. Both assume values between 160 and 320 for medium weight nuclei. For heavy nuclei they increase by almost a factor of two.

TABLE I

| 1<br>Nucleus | 2<br>E (0+) (Mev) | 3<br>AE (0+) | 4<br>E (2+) (Mev) | 5<br>AE (2+) | 6<br>E (2+′) (Mev) | 7<br>AE (2+′) | 8<br>E (3−)[a] (Mev) | 9<br>AE (3−) | 10<br>E (5−)[b] (Mev) | 11<br>AE (5−) | 12<br>Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ${}_{4}Be_{4}{}^{8}$ | 7·55 | 60·39 | 2·9 | 23·2 | .. | .. | .. | .. | .. | .. | 1 |
| ${}_{6}C_{6}{}^{12}$ | 7·66<br>10·1 | 91·91<br>121·1 | 4·43 | 53·16 | 9·62 | 115·4 | .. | .. | .. | .. | 2 |
| ${}_{8}O_{8}{}^{16}$ | 6·06 | 96·96 | 6·91 | 110·6 | .. | .. | 6·13 | 98·09 | .. | .. | 1 |
| ${}_{8}O_{10}{}^{18}$ | 3·627 | 65·28 | 1·98 | 35·65 | 3·915 | 70·47 | .. | .. | .. | .. | 3 |
| ${}_{10}Ne_{10}{}^{20}$ | 6·74<br>7·22 | 134·8<br>144·4 | 1·63 | 32·6 | 7·45 | 149·0 | .. | .. | .. | .. | 1 |
| ${}_{12}Mg_{12}{}^{24}$ | 6·44 | 154·5 | 1·367 | 32·78 | 4·23 | 101·5 | .. | .. | .. | .. | 4 |
| ${}_{14}Si_{14}{}^{28}$ | 4·98 | 137·8 | 1·78 | 49·83 | 6·88 | 192·7 | .. | .. | .. | .. | 5 |
| ${}_{14}Si_{16}{}^{30}$ | (3·765) | 112·9 | 2·23 | 66·89 | .. | .. | .. | .. | .. | .. | 5 |
| ${}_{16}S_{16}{}^{32}$ | 3·78 | 121·0 | 2·24 | 71·66 | 4·29 | 137·3 | .. | .. | .. | .. | 5 |
| ${}_{16}S_{18}{}^{34}$ | .. | .. | 2·127 | 72·31 | 3·22 | 109·5 | .. | .. | .. | .. | 1 |
| ${}_{18}Ar_{20}{}^{38}$ | .. | .. | 2·15 | 81·70 | .. | .. | .. | .. | .. | .. | 1 |
| ${}_{20}Ca_{20}{}^{40}$ | 3·35 | 134·0 | .. | .. | .. | .. | 3·37 | 149·2 | .. | .. | 1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $_{20}\mathrm{Ca}_{22}^{42}$ | .. | .. | 1·53 | 64·25 | .. | .. | .. | .. | .. | .. | 6 |
| $_{20}\mathrm{Ca}_{24}^{44}$ | (1·88) | 82·73 | 1·16 | 51·05 | 2·26 | 115·53 | .. | .. | .. | .. | 7 |
| $_{22}\mathrm{Ti}_{24}^{46}$ | .. | .. | 0·892 | 41·04 | .. | .. | .. | .. | .. | .. | 1 |
| $_{22}\mathrm{Ti}_{26}^{48}$ | .. | .. | 0·99 | 47·51 | .. | .. | .. | .. | .. | .. | 1 |
| $_{22}\mathrm{Ti}_{28}^{50}$ | .. | .. | 1·59 | 79·5 | .. | .. | .. | .. | .. | .. | 1 |
| $_{24}\mathrm{Cr}_{28}^{52}$ | .. | .. | 1·433 | 74·5 | 2·965 | 154·2 | .. | .. | .. | .. | 6 |
| $_{24}\mathrm{Cr}_{30}^{54}$ | .. | .. | 0·835 | 45·09 | .. | .. | .. | .. | .. | .. | 1 |
| $_{26}\mathrm{Fe}_{30}^{56}$ | .. | .. | 0·845 | 47·33 | .. | .. | .. | .. | .. | .. | 6 |
| $_{26}\mathrm{Fe}_{32}^{58}$ | .. | .. | 0·814 | 47·21 | 1·62 | 93·96 | .. | .. | .. | .. | 1 |
| $_{28}\mathrm{Ni}_{30}^{58}$ | .. | .. | 1·420 | 82·35 | .. | .. | 4·33 | 251·1 | .. | .. | 1 |
| $_{28}\mathrm{Ni}_{32}^{60}$ | .. | .. | 1·332 | 79·93 | 2·158 | 129·5 | 3·95 | 237·0 | .. | .. | 1 |
| $_{28}\mathrm{Ni}_{34}^{62}$ | .. | .. | 1·17 | 72·54 | 2·047 | 125·9 | 3·70 | 229·4 | .. | .. | 1 |
| $_{30}\mathrm{Zn}_{34}^{64}$ | .. | .. | 0·980 | 62·72 | 2·25 | 144·0 | 2·98 | 190·7 | .. | .. | 1 |
| $_{30}\mathrm{Zn}_{36}^{66}$ | .. | .. | 1·04 | 68·63 | 1·87 | 123·4 | 2·72 | 179·5 | .. | .. | 1 |
| $_{30}\mathrm{Zn}_{38}^{68}$ | .. | .. | 1·02 | 69·36 | .. | .. | 2·518 | 171·2 | .. | .. | 1 |
| $_{32}\mathrm{Ge}_{38}^{70}$ | 1·21 | 84·70 | 1·036 | 72·51 | .. | .. | .. | .. | .. | .. | 1 |
| $_{32}\mathrm{Ge}_{40}^{72}$ | 0·690 | 49·67 | 0·840 | 60·47 | 1·46 | 105·2 | .. | .. | .. | .. | 1 |
| $_{32}\mathrm{Ge}_{42}^{74}$ | .. | .. | 0·596 | 44·1 | (1·2) | 88·8 | .. | .. | .. | .. | 1 |

TABLE I (*Contd.*)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nucleus | E (0$^+$) (Mev) | AE (0$^+$) | E (2$^+$) (Mev) | AE (2$^+$) | E (2$^{+\prime}$) (Mev) | AE (2$^{+\prime}$) | E (3$^-$)$^a$ (Mev) | AE (3$^-$) | E (5$^-$)$^b$ (Mev) | AE (5$^-$) | Reference |
| $_{34}Se_{42}{}^{76}$ | .. | .. | 0·561 | 42·64 | 1·22 | 92·72 | .. | .. | .. | .. | 1 |
| $_{34}Se_{44}{}^{78}$ | .. | .. | 0·615 | 47·97 | 1·307 | 101·7 | .. | .. | .. | .. | 1 |
| $_{34}Se_{46}{}^{80}$ | .. | .. | 0·667 | 53·35 | 1·455 | 116·4 | .. | .. | .. | .. | 8 |
| $_{36}Kr_{44}{}^{80}$ | .. | .. | 0·618 | 49·44 | 1·258 | 100·7 | .. | .. | .. | .. | 8 |
| $_{36}Kr_{46}{}^{82}$ | .. | .. | 0·777 | 63·71 | 1·475 | 121·0 | .. | .. | .. | .. | 6 |
| $_{36}Kr_{48}{}^{84}$ | .. | .. | 0·88 | 73·92 | 1·9 | 159·6 | .. | .. | .. | .. | 1 |
| $_{38}Sr_{48}{}^{86}$ | .. | .. | 1·084 | 93·24 | 1·925 | 165·5 | .. | .. | .. | .. | 9 |
| $_{38}Sr_{50}{}^{88}$ | .. | .. | 1·85 | 162·9 | 4·2 | 369·6 | 2·76 | 242·9 | .. | .. | 1 |
| $_{40}Zr_{50}{}^{90}$ | 1·734 | 156·1 | 2·18 | 196·2 | .. | .. | 2·2 | 198·0 | 2·32 | 208·7 | 6 |
| $_{40}Zr_{52}{}^{92}$ | 2·26 | 207·9 | 2·71 | 249·4 | 1·81 | 166·5 | .. | .. | .. | .. | 10 |
| $_{42}Mo_{52}{}^{94}$ | .. | .. | 0·874 | 82·15 | 1·57 | 147·6 | .. | .. | .. | .. | 6 |
| $_{42}Mo_{54}{}^{96}$ | .. | .. | 0·77 | 73·92 | 1·61 | 154·5 | .. | .. | .. | .. | 11 |
| $_{44}Ru_{54}{}^{98}$ | .. | .. | 0·654 | 64·09 | 1·39 | 136·2 | .. | .. | .. | .. | 6 |
| $_{44}Ru_{56}{}^{100}$ | .. | .. | 0·535 | 53·5 | 1·358 | 135·8 | .. | .. | .. |  | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| ${}_{46}Pd_{58}{}^{104}$ | 1·05 | 109·1 | 0·556 | 57·82 | 1·34 | 139·3 | .. | .. | .. | .. | 1 |
| ${}_{46}Pd_{60}{}^{106}$ | 1·14 | 120·9 | 0·51 | 54·06 | 1·13 | 119·7 | 2·883 | 220·8 | .. | .. | 12 |
| ${}_{46}Pd_{62}{}^{108}$ | 1·05 | 113·4 | 0·43 | 46·44 | 0·941 | 101·6 | 1·987 | 214·6 | .. | .. | 13 |
| ${}_{48}Cd_{60}{}^{108}$ | .. | .. | 6·30 | .. | .. | .. | 2·19 | 236·4 | 2·54 | 274·3 | .. |
| ${}_{48}Cd_{62}{}^{110}$ | .. | .. | 0·656 | 72·16 | 1·474 | 162·1 | 2·056 | 226·2 | 2·92 | 321·2 | 14 |
| ${}_{48}Cd_{64}{}^{112}$ | 1·23<br>1·43 | 137·7<br>160·2 | 0·610 | 68·31 | 1·30 | 145·5 | 1·96 | 219·6 | .. | .. | 15 |
| ${}_{48}Cd_{66}{}^{114}$ | 1·133<br>1·304 | 129·1<br>148·6 | 0·557 | 63·51 | 1·208 | 137·4 | 1·946 | 221·8 | .. | .. | 16 |
| ${}_{50}Sn_{64}{}^{114}$ | .. | .. | 1·299 | 148·01 | .. | .. | 3·508 | 251·1 | .. | .. | 6 |
| ${}_{50}Sn_{66}{}^{116}$ | 1·72 | 199·5 | 1·27 | 147·2 | 2·09 | 242·4 | 2·24 | 259·8 | .. | .. | 17 |
| ${}_{50}Sn_{68}{}^{118}$ | .. | .. | 1·22 | 144·0 | .. | .. | 2·23 | 269·0 | 2·29 | 270·2 | 6 |
| ${}_{50}Sn_{70}{}^{120}$ | .. | .. | 1·18 | 141·6 | .. | .. | 2·38 | 285·2 | 2·29 | 274·8 | 6 |
| ${}_{50}Sn_{72}{}^{122}$ | .. | .. | 1·14 | 134·1 | .. | .. | 2·50 | 305·4 | .. | .. | 6 |
| ${}_{50}Sn_{74}{}^{124}$ | .. | .. | 1·13 | 140·2 | .. | .. | 2·55 | 316·1 | .. | .. | 6 |
| ${}_{52}Te_{70}{}^{122}$ | .. | .. | 0·564 | 68·82 | 1·26 | 153·8 | .. | .. | .. | .. | 6 |
| ${}_{52}Te_{72}{}^{124}$ | .. | .. | 0·603 | 74·76 | 1·35 | 167·4 | 2·253 | 279·4 | .. | .. | 6 |
| ${}_{52}Te_{74}{}^{126}$ | .. | .. | 0·66 | 83·06 | 1·41 | 177·6 | 2·31 | 191·1 | .. | .. | 6 |

TABLE I (*Contd.*)

| 1<br>Nucleus | 2<br>E $(0^+)$ (Mev) | 3<br>AE $(0^+)$ | 4<br>E $(2^+)$ (Mev) | 5<br>AE $(2^+)$ | 6<br>E $(2^{+\prime})$ (Mev) | 7<br>AE $(2^{+\prime})$ | 8<br>E $(3^-)^a$ (Mev) | 9<br>AE $(3^-)$ | 10<br>E $(5^-)^b$ (Mev) | 11<br>AE $(5^-)$ | 12<br>Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ${}_{52}Te_{76}{}^{128}$ | .. | .. | 0·75 | 96·01 | .. | .. | 2·45 | 313·6.. | .. | .. | 6 |
| ${}_{52}Te_{78}{}^{130}$ | .. | .. | 0·85 | 110·5 | .. | .. | 2·32 | 301·6 | .. | .. | 6 |
| ${}_{54}Xe_{72}{}^{126}$ | .. | .. | 0·386 | 47·53 | 0·86 | 108·3 | .. | .. | .. | .. | 6 |
| ${}_{54}X_{74}e^{128}$ | .. | .. | 0·45 | 57·59 | 0·98 | 125·4 | .. | .. | .. | .. | 6 |
| ${}_{54}X_{76}e^{130}$ | .. | .. | 0·528 | 68·63 | .. | .. | 1·998 | 259·8 | 2·34 | 304·2 | 6 |
| ${}_{54}Xe_{78}{}^{132}$ | .. | .. | 0·673 | 88·84 | 1·26 | 166·3 | .. | .. | .. | .. | 6 |
| ${}_{54}Xe_{82}{}^{136}$ | .. | .. | 1·32 | 179·5 | 2·6 | 353·6 | .. | .. | .. | .. | 6 |
| ${}_{56}Ba_{78}{}^{134}$ | .. | .. | 0·605 | 81 08 | 1·168 | 156·5 | .. | .. | .. | .. | 6 |
| ${}_{56}Ba_{80}{}^{136}$ | .. | .. | 1·041 | 141·6 | .. | .. | 2·98 | 405·2 | .. | .. | 1 |
| ${}_{56}Ba_{82}{}^{138}$ | .. | .. | 1·43 | 197·3 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{58}Ce_{82}{}^{140}$ | 1·902 | 266·3 | 1·596 | 223·5 | 2·349 | 328·7 | 2·46 | 344·3 | .. | .. | 18 |
| ${}_{60}Nd_{82}{}^{142}$ | .. | .. | 1·57 | 222·9 | .. | .. | 2·08 | 295·4 | .. | .. | 6 |
| ${}_{60}Nd_{84}{}^{144}$ | .. | .. | 0·69 | 99·36 | 1·22 | 175·7 | 1·504 | 216·6 | .. | .. | 19 |
| ${}_{60}Nd_{86}{}^{146}$ | .. | .. | 0·455 | 66·43 | .. | .. | 1·22 | 178·1 | .. | .. | 1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ${}_{60}\mathrm{Nd}_{88}^{148}$ | .. | .. | 0·3 | 44·4 | .. | .. | 1·01 | 149·4 | .. | .. | 6 |
| ${}_{60}\mathrm{Nd}_{90}^{150}$ | .. | .. | 0·131 | 19·65 | .. | .. | 0·981 | 147·2 | .. | .. | 6 |
| ${}_{62}\mathrm{Sm}_{86}^{148}$ | .. | .. | 0·562 | 83·18 | .. | .. | 1·182 | 175·0 | .. | .. | 6 |
| ${}_{62}\mathrm{Sm}_{88}^{150}$ | 0·741 | 111·1 | 0·334 | 50·09 | 0·736 | 110·4 | 1·067 | 159·7 | .. | .. | 20 |
| ${}_{62}\mathrm{Sm}_{90}^{152}$ | 0·685 | 104·1 | 1·22 | 185·5 | 1·092 | 166·0 | 1·067 | 159·7 | .. | .. | 6 |
| ${}_{64}\mathrm{Gd}_{88}^{152}$ | 0·615<br>(1·047) | 93·48<br>159·2 | 0·344 | 52·29 | 0·929 | 141·2 | .. | .. | .. | .. | 6 |
| ${}_{64}\mathrm{Gd}_{90}^{154}$ | .. | .. | 0·123 | 18·94 | 0·998 | 153·7 | .. | .. | .. | .. | 6 |
| ${}_{64}\mathrm{Gd}_{92}^{156}$ | 0·87 | 135·7 | 0·089 | 13·89 | 1·14 | 177·8 | .. | .. | .. | .. | 21 |
| ${}_{66}\mathrm{Dy}_{92}^{158}$ | .. | .. | 0·0993 | 15·69 | .. | .. | .. | .. | .. | .. | 22 |
| ${}_{66}\mathrm{Dy}_{94}^{160}$ | .. | .. | 0·087 | 13·92 | 0·964 | 154·3 | .. | .. | .. | .. | 6 |
| ${}_{66}\mathrm{Dy}_{96}^{162}$ | .. | .. | 0·081 | 13·12 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{66}\mathrm{Dy}_{98}^{164}$ | .. | .. | 0·0728 | 11·93 | .. | .. | .. | .. | .. | .. | 1 |
| ${}_{68}\mathrm{Er}_{98}^{166}$ | 1·062 | 176·3 | 0·0811 | 13·46 | 1·541 | 255·8 | .. | .. | .. | .. | 1 |
| ${}_{68}\mathrm{Er}_{100}^{168}$ | .. | .. | 0·080 | 13·44 | .. | .. | .. | .. | .. | .. | 1 |
| ${}_{69}\mathrm{Tm}_{103}^{172}$ | 0·538 | 92·53 | .. | .. | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{70}\mathrm{Yb}_{102}^{172}$ | .. | .. | 0·079 | 13·5 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{72}\mathrm{Hf}_{104}^{176}$ | .. | .. | 0·089 | 15·66 | .. | .. | .. | .. | .. | .. | 1 |

TABLE I (*Contd.*)

| 1<br>Nucleus | 2<br>E (0+) (Mev) | 3<br>AE (0+) | 4<br>E (2+) (Mev) | 5<br>AE (2+) | 6<br>E (2+′) (Mev) | 7<br>AE (2+′)$^a$ | 8<br>E (3−) (Mev) | 9<br>AE (3−) | 10<br>E (5−)$^b$ (Mev) | 11<br>AE (5−) | 12<br>Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ${}_{72}Hf_{106}{}^{178}$ | 1·197<br>(1·44) | 213·0<br>256·9 | 0·0932 | 16·56 | 1·277 | 226·8 | .. | .. | .. | .. | 23 |
| ${}_{72}Hf_{108}{}^{180}$ | .. | .. | 0·0933 | 16·8 | .. | .. | .. | .. | .. | .. | 1 |
| ${}_{74}W_{108}{}^{182}$ | .. | .. | 0·1009 | 18·35 | 1·222 | 222·4 | 1·374 | 250·1 | 1·62 | 294·8 | 1 |
| ${}_{74}W_{110}{}^{184}$ | .. | .. | 0·111 | 20·42 | 0·904 | 166·3 | .. | .. | .. | .. | 6 |
| ${}_{74}W_{112}{}^{186}$ | .. | .. | 0·125 | 23·25 | 0·73 | 135·8 | .. | .. | .. | .. | 1 |
| ${}_{76}Os_{110}{}^{186}$ | .. | .. | 0·137 | 25·48 | 0·768 | 142·9 | .. | .. | .. | .. | 6 |
| ${}_{76}Os_{112}{}^{188}$ | 1·086 | 204·2 | 0·155 | 29·14 | 0·633 | 119·2 | .. | .. | .. | .. | 24 |
| ${}_{76}Os_{114}{}^{190}$ | .. | .. | 0·187 | 35·53 | 0·558 | 106·0 | .. | .. | .. | .. | 6 |
| ${}_{76}Os_{116}{}^{192}$ | .. | .. | 0·206 | 39·56 | 0·489 | 93·89 | .. | .. | .. | .. | 6 |
| ${}_{78}Pt_{114}{}^{192}$ | .. | .. | 0·317 | 60·87 | 0·613 | 117·7 | .. | .. | .. | .. | 6 |
| ${}_{78}Pt_{116}{}^{194}$ | 1·265 | 245·4 | 0·328 | 63·63 | 0·621 | 120·5 | .. | .. | .. | .. | 6 |
| ${}_{78}Pt_{118}{}^{196}$ | .. | .. | 0·356 | 69·77 | 0·689 | 135·1 | .. | .. | .. | .. | 6 |
| ${}_{80}Hg_{118}{}^{198}$ | 1·082 | 244·2 | 0·412 | 81·58 | 1·09 | 215·8 | .. | .. | .. |  | 6 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ${}_{80}\mathrm{Hg}_{120}{}^{200}$ | .. | .. | 0·368 | 73·57 | 1·575 | 315·0 | .. | .. | .. | .. | 6 |
| ${}_{82}\mathrm{Pb}_{122}{}^{202}$ | .. | .. | 0·899 | 181·7 | .. | .. | 1·374 | .. | 2·04 | 412·1 | 6 |
| ${}_{82}\mathrm{Pb}_{124}{}^{206}$ | .. | .. | 0·803 | 165·4 | .. | .. | 2·525 | 520·2 | 2·8 | 576·9 | 6 |
| ${}_{82}\mathrm{Pb}_{126}{}^{208}$ | .. | .. | .. | .. | .. | .. | 2·614 | 543·8 | 3·2<br>3·71 | 665·6<br>771·8 | |
| ${}_{84}\mathrm{Po}_{126}{}^{210}$ | .. | .. | 1·181 | 248·0 | .. | .. | .. | .. | 2·91 | 611·0 | 6 |
| ${}_{84}\mathrm{Po}_{128}{}^{212}$ | 1·68 | 356·1 | 1·27 | 269·3 | 1·513 | 320·7 | .. | .. | .. | .. | 25 |
| ${}_{84}\mathrm{Po}_{130}{}^{216}$ | 1·416 | 303·0 | 0·609 | 130·3 | 1·847 | 395·4 | .. | .. | .. | .. | 6 |
| ${}_{84}\mathrm{Po}_{132}{}^{210}$ | .. | .. | 0·544 | 117·0 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{86}\mathrm{Rn}_{132}{}^{218}$ | .. | .. | 0·235 | 70·86 | (0·65) | 14·14 | .. | .. | .. | .. | 6 |
| ${}_{86}\mathrm{Rn}_{134}{}^{220}$ | .. | .. | 0·241 | 53·02 | (0·53) | 116·6 | .. | .. | .. | .. | 6 |
| ${}_{86}\mathrm{Rn}_{136}{}^{222}$ | .. | .. | 0·187 | 41·52 | (0·447) | 99·24 | .. | .. | .. | .. | 6 |
| ${}_{88}\mathrm{Ra}_{136}{}^{224}$ | .. | .. | 0·084 | 18·81 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{88}\mathrm{Ra}_{138}{}^{226}$ | .. | .. | 0·068 | 15·37 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{90}\mathrm{Th}_{138}{}^{228}$ | .. | .. | 0·057 | 12·99 | (0·965) | 220·0 | .. | .. | .. | .. | 6 |
| ${}_{90}\mathrm{Th}_{140}{}^{230}$ | .. | .. | 0·053 | 12·19 | (1·06) | 243·8 | .. | .. | .. | .. | 6 |
| ${}_{92}\mathrm{U}_{140}{}^{232}$ | 0·693 | 160·8 | 0·0476 | 11·04 | 0·735 | 170·5 | .. | .. | .. | .. | 26 |
| ${}_{92}\mathrm{U}_{142}{}^{234}$ | 0·811 | 189·8 | 1·045 | 244·5 | 0·0435 | 10·18 | .. | .. | .. | .. | 27 |

TABLE I—(*Contd.*)

| 1<br>Nucleus | 2<br>E (0+) (Mev) | 3<br>AE (0+) | 4ρ<br>E (2+) (Mev) | 5<br>AE (2+) | 6<br>E (2+') (Mev) | 7<br>AE (2+') | 8<br>E (3−)$^a$ (Mev) | 9<br>AE (3−) | 10<br>E (5−)$^b$ (Mev) | 11<br>AE (5−) | 12<br>Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ${}_{92}U_{144}^{238}$ | .. | .. | 0·045 | 10·86 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{94}Pu_{144}^{238}$ | 0·94 | 223·8 | 0·044 | 10·23 | 1·03 | 245·1 | .. | .. | .. | .. | 6 |
| ${}_{94}Pu_{146}^{240}$ | (0·94) | 225·6 | 0·0428 | 10·27 | (1·02) | 244·8 | .. | .. | .. | .. | 6 |
| ${}_{94}Pu_{148}^{242}$ | .. | .. | 0·045 | 10·89 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{96}Cm_{150}^{246}$ | .. | .. | 0·043 | 10·58 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{96}Cm_{152}^{248}$ | .. | .. | 0·043 | 10·67 | .. | .. | .. | .. | .. | .. | 6 |
| ${}_{98}Cf_{152}^{250}$ | .. | .. | 0·042 | 10·5 | (1·2) | 300 | .. | .. | .. | .. | 6 |

*Note.*—Data for E (3−) and E (5−) are taken from the following references:—

(*a*) O. Hansen and O. Nathan, *Nucl. Phy.*, 1963, **42**, 197.

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The above-mentioned systematics may possibly help to classify excited levels by means of the product AE and the range in which this product lies. The above discussion can be summarised as shown in Table II.

TABLE II

| Excited state | Range of AE for |  | Remarks |
|---|---|---|---|
|  | Light-weight and Medium-weight nuclei | Deformed and heavy-weight nuclei |  |
| $0^+$ | 80–200 | 180–360 | Sensitive to shell-closure and magic numbers. |
| $0^{+\prime}$ | 140–160 |  | (i) Insensitive to shell-closure and magic numbers.<br>(ii) AE ($0^{+\prime}$) closer to AE ($2^{+\prime}$) than AE ($2^+$). |
| $2^+$ | 30–140 | 10–40 | (i) Sensitive to shell-closure and magic numbers.<br>(ii) AE ($2^+$) remains almost constant ($\approx 10$) for deformed and heavy-weight nuclei. |
| $2^{+\prime}$ | 100–180 | No definite range | (i) Sensitive to shell-closure and magic numbers.<br>(ii) AE ($2^{+\prime}$) is twice that of AE ($2^+$) approx. for light and medium-weight nuclei<br>(iii) AE ($2^{+\prime}$) goes on increasing for deformed and heavy nuclei. |
| $3^-$ and $5^-$ | 160–320 | 500–700 | (i) Insensitive to shell closure and magic numbers.<br>(ii) The value of AE for heavy nuclei is nearly twice that for medium-weight nuclei. |

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