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Lifetime measurements for levels in ^{30}P between 3·7 and 4·7 MeV excitation energy†

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Abstract. The mean lifetimes of nine levels in ^{30}P, between 3·7 and 4·7 MeV excitation energy, have been measured using the Doppler shift attenuation method. A limit has also been placed on the lifetime of one further level. Three of these lifetimes have not previously been measured, these are 40 ± 30 fs, 180^{+60}_{-50} fs and 185 ± 15 fs for the 4235, 4298 and 4343 keV levels respectively. A doublet has been found at $4229{\cdot}9 \pm 1{\cdot}3$ keV and $4234{\cdot}5 \pm 1{\cdot}8$ keV where only a single level had been previously reported. The measured lifetimes give transition strengths which lead to spin assignments of 2^+ and 3 for the 3834 and 3927 keV levels respectively.

1. Introduction

The lifetimes of levels in ^{30}P below 3·7 MeV excitation energy have recently been measured in this laboratory (Sharpey-Schafer *et al* 1971) using the Doppler shift attenuation method, the levels being populated by the ^{27}Al(α, n)^{30}P reaction. We report here an extension of these measurements to determine the lifetimes of levels between 3·7 and 4·7 MeV excitation energy. Most of the information on the levels of ^{30}P in this region comes from the ^{29}Si(p, γ)^{30}P (eg Harris *et al* 1969) and ^{28}Si(^{3}He, p)^{30}P (eg Vermette *et al* 1968) reactions. There is disagreement between the two methods on the decay of the 4231 keV level; the use of a different reaction should clarify the situation. Our lifetime measurements will provide a useful check on those obtained from the ^{29}Si(p, γ)^{30}P reaction (Graves and McDaniels 1969, Harris *et al* 1969 and Bini *et al* 1971) and also give some information on levels not populated in that reaction.

2. Apparatus and experimental method

A 1·66 mg cm^{-2} Al foil mounted on a gold backing was bombarded by 9 MeV α particles. At this energy levels in ^{30}P up to 4·7 MeV excitation energy and many levels in ^{30}Si, via the ^{27}Al(α, p)^{30}Si reaction, were populated. The γ rays were detected at six angles θ between 0° and 125° relative to the beam direction using an escape suppressed and pair escape spectrometer. The spectrometer was calibrated and the gain and zero stability monitored using a ^{56}Co source. No gain shifts were observed during the experiment, but corrections of less than half a channel have been introduced at some angles for

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zero shifts. A least squares linear fit was performed to the γ ray centroid against $\cos\theta$ data to give the attenuation factors. The mean α particle energy in the target was $(8{\cdot}7\pm0{\cdot}1)$ MeV, which gives an initial recoil velocity of $(0{\cdot}887\pm0{\cdot}015)\%$ of the velocity of light. The lifetimes were found from a calculation of the attenuation factor F as a function of the lifetime τ using the formalism of Blaugrund (1966) and the stopping theory of Lindhard *et al* (1963).

3. Results

The excitation energies measured in this experiment are given in table 1. These are generally in agreement with previous measurements, the differences being the 3729 keV level which Harris *et al* (1969) report as 3736 ± 3 keV and the doublet at 4230 keV

Table 1. Measured level energies, attenuation factors and lifetimes in ^{30}P

Level energy (keV)	E_γ (keV)	F	τ(fs)			
			Present ($\pm25\%$)†	Graves and McDaniels (1969)	Harris *et al* (1969)	Bini *et al* (1971)
$3729{\cdot}2\pm1{\cdot}5$	793	$0{\cdot}92\pm0{\cdot}05$	55 ± 35	19^{+6}_{-8}		
$3834{\cdot}3\pm1{\cdot}3$	898	$0{\cdot}95\pm0{\cdot}02$	32^{+15}_{-12}	44 ± 7		
$3927{\cdot}2\pm1{\cdot}3$	991	$0{\cdot}82\pm0{\cdot}02$	125^{+20}_{-13}	100^{+25}_{-16}		
$4144{\cdot}3\pm1{\cdot}3$	4144	$0{\cdot}92\pm0{\cdot}02$	52^{+15}_{-12}	46 ± 8	58 ± 14	25 ± 9
$4182{\cdot}7\pm1{\cdot}5$	3474	$>0{\cdot}97$	<20	$\leqslant24$		<20
$4229{\cdot}9\pm1{\cdot}3$	1692	$0{\cdot}38\pm0{\cdot}03$	740 ± 90	1800^{+2700}_{-700}	>1200	>1300
$4234{\cdot}5\pm1{\cdot}8$	2781	$0{\cdot}94\pm0{\cdot}04$	40 ± 30			
4298 ± 5	2845	$0{\cdot}75\pm0{\cdot}06$	180^{+60}_{-50}			
$4342{\cdot}8\pm1{\cdot}0$	2370	$0{\cdot}75\pm0{\cdot}02$	185 ± 15			
$4624{\cdot}9\pm1{\cdot}5$	3171	$0{\cdot}71\pm0{\cdot}02$	220 ± 20		260 ± 60	280 ± 60

† The uncertainty in the stopping theory is shown as a 25 % error in the time scale.

which they report as a single level at 4231 ± 2 keV. The decay scheme for levels in ^{30}P below 4·7 MeV excitation energy is shown in figure 1. Attenuation factors and lifetimes are also given in table 1. Our lifetimes, presented in column four, contain only the experimental errors. Uncertainty in the stopping theory is shown as a 25 % error in the time scale. The results for each level are discussed below.

3.1. The 3729, 3834 and 3927 keV levels

These have each been assigned spin 1, 2 or 3 by Vermette *et al* (1968). In each case we have taken our measurement from the decay to the 2^+ 2936 keV level, the branching ratios are 7 %, 65 % and 47 % respectively (B E Crossfield *et al* 1971, private communication). The F factor of the 793 keV γ ray has larger errors as it lies near the Compton edge of the 1014 keV γ ray from the ground state decay of the second excited state in ^{27}Al. Our lifetimes are in agreement with the results of Graves and McDaniels

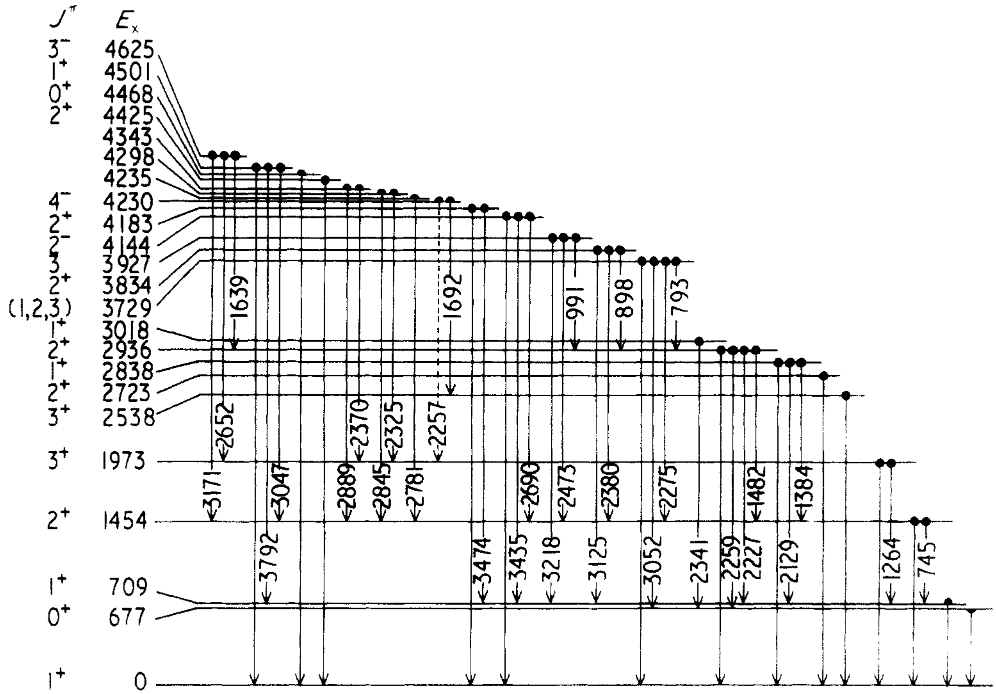

Figure 1. Decay scheme for levels of ^{30}P below 4·7 MeV excitation energy. The data used are taken from the present experiment, Harris *et al* (1969) and Vermette *et al* (1968).

(1969). Using the multipole mixing ratios given by Vermette *et al* (1968) and our lifetimes, transition strengths have been calculated. We find that for the 3834 keV level the only mixing ratio to give a reasonable value for either the E2 or M2 strength is $-0{\cdot}58 \leqslant \delta \leqslant 0{\cdot}38$ which corresponds to a spin 2 hypothesis. We can also assign even parity to this level as the E1 strength obtained is greater than $1{\cdot}5 \times 10^{-2}$ Wu (Weisskopf single particle units). Similarly for the 3927 keV level the only mixing ratio to give reasonable transition strengths is $\delta = 0^{+0{\cdot}14}_{-0{\cdot}06}$ which corresponds to a spin 3 hypothesis. In this case the E1 and M1 strengths are $(3{\cdot}9 \pm 0{\cdot}5) \times 10^{-3}$ Wu and $0{\cdot}12^{+0{\cdot}01}_{-0{\cdot}02}$ Wu respectively.

3.2. *The 4144 keV level*

The 4144 keV γ ray from the ground state decay of this level is just resolved at all angles from the 4112 keV γ ray from the decay of the 7610 keV level in ^{30}Si. Our lifetime of 52^{+15}_{-12} fs is in agreement with most previous measurements (table 1). This 2^- level decays to the 1^+ ground state with a pure E1 strength of $(1{\cdot}9^{+0{\cdot}6}_{-0{\cdot}4}) \times 10^{-4}$ Wu.

3.3. *The 4183 keV level*

The 3474 keV γ ray from the decay of this level to the 1^+ 709 keV level lies close to the 3498 keV γ ray from the ground state decay of the second excited state in ^{30}Si. It is sufficiently resolved at 90°, 110° and 125° to allow a lifetime measurement to be made. Our limit of less than 20 fs agrees with the limits set in previous measurements (table 1).

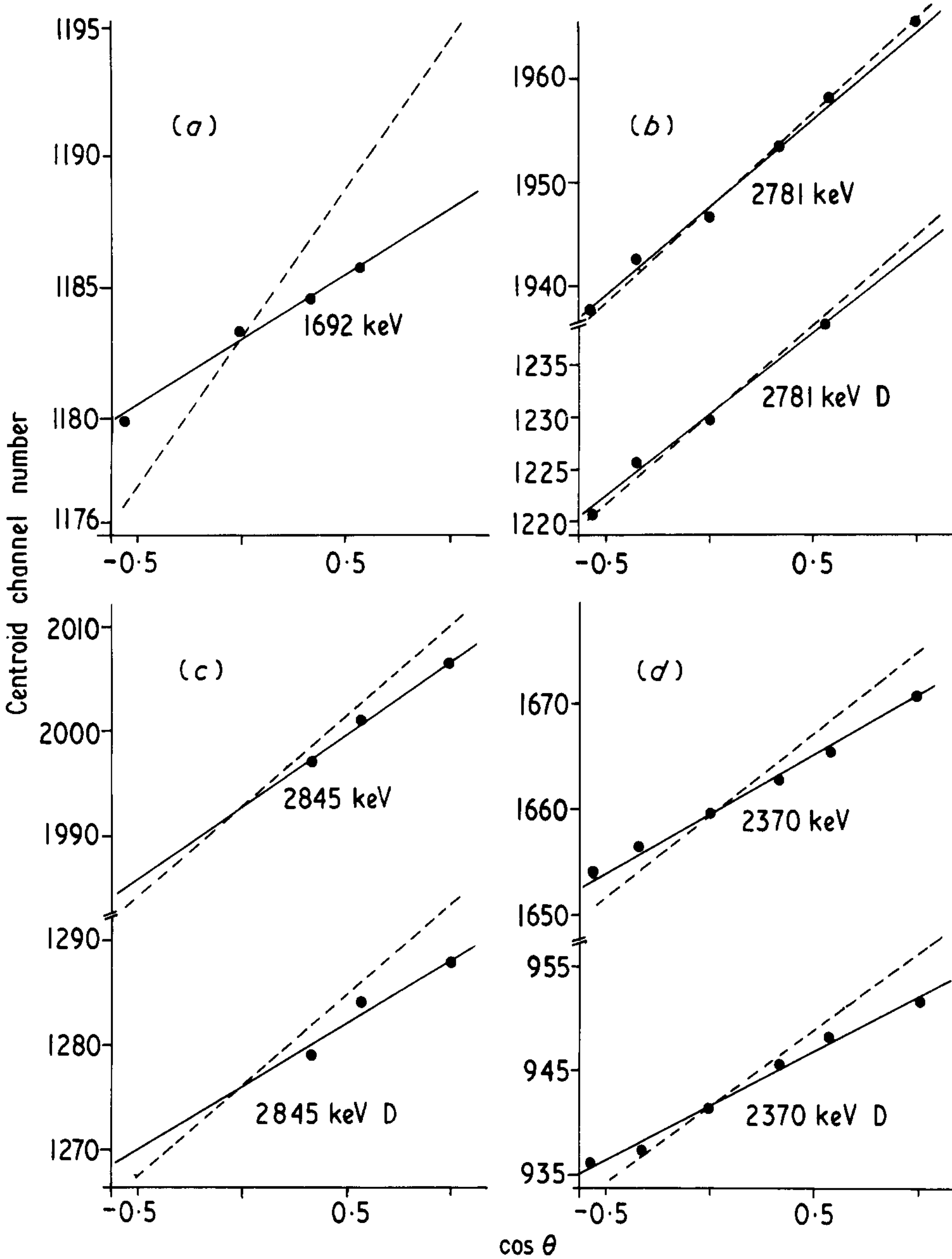

Figure 2. Plots of γ ray centroid against cos θ. (*a*) 4230 keV level, $F = 0{\cdot}38 \pm 0{\cdot}03$; (*b*) 4235 keV level, $F = 0{\cdot}94 \pm 0{\cdot}04$; (*c*) 4298 keV level, $F = 0{\cdot}75 \pm 0{\cdot}06$; (*d*) 4343 keV level, $F = 0{\cdot}75 \pm 0{\cdot}02$. Least squares fits to the data are shown as full lines. The full shifts, corresponding to $F = 1$, are shown as broken lines. Data for double escape peaks are indicated by D. The dispersion is 1·42 keV per channel.

3.4. The 4230 and 4235 keV levels

Harris *et al* (1969) and Vermette *et al* (1968) disagree on the decay scheme of their 4^- 4231 keV level. They both have the major part of the decay to the 1973 and 2538 keV levels. Harris *et al* (1969) then give a 4% branch to the ground state and a 3% branch to the 2838 keV level, while Vermette *et al* (1968) give a 12% branch to the 1454 keV level. We observe γ rays with energies of 2781 and 1692 keV which can only be assigned as decays from these levels to the 1454 and 2538 keV levels. The decay to the 1973 keV level is contaminated by the decay of the 2937 keV level and the ground state decay of the first excited state in ^{30}Si. The decay to the 2538 keV level gives a lifetime of 740 ± 90 fs and a level energy of $4229{\cdot}9 \pm 1{\cdot}3$ keV. The decay to the 1454 keV level gives a lifetime of 40 ± 30 fs and a level energy of $4234{\cdot}5 \pm 1{\cdot}8$ keV. Plots of γ ray centroid against $\cos\theta$ for these levels are shown in figure 2. It appears that the 4^- level found by Harris *et al* (1969) is at 4230 keV and decays to the 2538 keV level and the new 4235 keV level decays to the 1454 keV level.

3.5. The 4298 and 4343 keV levels

Little is known about these two levels. The 2845 keV γ ray from the decay of the 4298 keV level to the 1454 keV level is resolved from the ground state decay of the 2838 keV level only as 0°, 55°, 70° from which we obtain a lifetime of 180^{+60}_{-50} fs. The energy of this level was found by extrapolating the line fitted to the γ ray centroid against $\cos\theta$ data to $\theta = 90°$; the resulting energy has larger errors than those measured directly. The 2370 keV γ ray from the decay of the 4343 keV level gives a lifetime of 185 ± 15 fs. Plots of γ ray centroid against $\cos\theta$ for these levels are shown in figure 2.

3.6. The 4625 keV level

Measurements were taken at four angles for the 3171 keV γ ray. The lifetime of 220 ± 20 fs agrees with previous measurements (table 1). The decay of this 3^- level to the 2^+ 1454 keV level is pure E1 with a strength of $(1{\cdot}0 \pm 0{\cdot}1) \times 10^{-4}$ Wu.

4. Conclusions

The $^{27}Al(\alpha, n)^{30}P$ reaction has been used to provide more information on the levels in ^{30}P between 3·7 and 4·7 MeV excitation energy. We find a doublet at 4·23 MeV where a single level has been previously reported, this explains the disagreement on the decay scheme of this level. The lifetimes of three states not populated in the $^{29}Si(p, \gamma)^{30}P$ reaction have been found and with the exception of the 4230 keV level the remainder of our results are in agreement with the results from the $^{29}Si(p, \gamma)^{30}P$ reaction where smaller recoil velocities are involved. The levels at 3834 and 3927 keV have been assigned spins 2^+ and 3 respectively.

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