equal yields an integrated cross section of (6500_{-3000}^{+6000}) Mev-mb. The value from neutron yield measurements is 4800 Mev-mb.[42] Although the errors in our determination are large, we are gratified that we are able to make any measurement of the giant resonance in a heavy element where the elastic scattering is so strong. The fact that the ratio of the giant resonance peak to the elastic peak is about the same in Si and Pb suggests that when the experimental problem of the extraneous background is solved, the giant resonance in all elements can be investigated fruitfully by the method of inelastic electron scattering.

ACKNOWLEDGMENTS

We wish to thank W. R. Dodge and G. Peterson for their help in constructing and operating the equipment. Three of us (FB, GF, FEG) wish to acknowledge the support of the German Bundesministerium für Atomkernenergie und Wasserwirtschaft, which made possible our stay at Stanford, and to thank Dr. W. K. H. Panofsky for his hospitality in making the facilities of the High-Energy Physics Laboratory available to us.

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PHYSICAL REVIEW VOLUME 120, NUMBER 6 DECEMBER 15, 1960

Parameters of Some Low-Energy Neutron Resonances in Platinum*

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(Received August 5, 1960)

Measurements of the elastic scattering of neutrons from thin platinum foils were made as a function of neutron energy using a time-of-flight technique. Scattering areas were obtained for the 11.9, 19.6, 68, and 96-ev resonances. These were combined with a thick-sample transmission measurement and transmission data from other workers to give values for the parameters of the resonances. Level spins and partial widths were derived by a least squares method.

INTRODUCTION

MEASUREMENTS of the high-energy γ-ray spectra following neutron capture in platinum have been used to obtain values for the spins of the neutron resonances.[1–5] By combining this information with the results of transmission experiments, it is possible to arrive at other resonance parameters, such as the partial widths. However, the values obtained by this method are sometimes of poor accuracy due to the experimental uncertainty in the measured transmission areas. If neutron scattering measurements are performed, these data may be combined with the transmission areas to give an independent measurement of the level spin and also to obtain the other parameters with greater accuracy.

METHOD

The experimental method has been described in detail before[6,7]; it consists, briefly, of the measurement of the elastic scattering of neutrons from thin samples of natural platinum as a function of neutron energy. A time-of-flight technique is used for the neutron energy determination. Thin samples must be used since the data are to be extrapolated to zero sample thickness to remove the effect of multiple scattering and self-absorption in the material. The combination of the resulting information with that obtained from neutron transmission experiments enables values of the spin of the excited level, J, the total, radiation, and neutron widths Γ, Γ_γ, Γ_N, respectively, to be obtained.

The scattering experiments were performed using the 15-Mev electron linear accelerator[8] at the Atomic Energy Research Establishment, Harwell, England, as a neutron source for time-of-flight measurements. An annular ring of 18 2-in. diameter by 16-in. long BF_3 counters was used as the detector with the sample at

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* Part of this work was supported by the U. S. Atomic Energy Commission.

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the center. The flight path was varied from 6 to 19 meters to suit the resonance under study. The counters were heavily shielded with $1\frac{1}{2}$ tons of boric oxide to reduce the background. The scattering from a pure lead sample was used to calibrate the detector, assuming a cross section of 11.4 barns for lead. Further experimental details may be found in reference 6.

The counting rate of the detector was recorded as a function of the neutron delay, and, after correction for background, divided by the counting rate from the lead sample of known transmission. Three independent neutron monitors were used to ensure good correlation between the various runs.

The area under the resonance peak in the time-of-flight curve was measured for several target thicknesses and a quantity S' (proportional to the peak area divided by the target thickness) plotted as a function of target thickness. Due to the loss in counts from multiple scattering and neutron capture in the sample, the measured areas are less than they should be, or, in other words, S' decreases with increasing target thickness. Figure 1 shows a plot of S' against the target thickness for the 11.9-ev resonance. The target thicknesses used were 0.001 in., 0.002 in., 0.004 in., and 0.006 in.

To get the correct value of S' to be taken, the measured values were extrapolated to zero target thickness. Attempts were made[7] to correct the individual values of S' to zero thickness (see Fig. 1) using the curves of Hughes,[9] but these are not very successful at this low neutron energy where $\Gamma_\gamma \gg \Gamma_N$. The extrapolated value of S', called S, can be shown[6,7] to be equal to $g\Gamma_N^2/\Gamma$, where g is the statistical weight factor $g=\frac{1}{2}[1+1/(2I+1)]$, I being the spin of the target nucleus.

The resonance areas, T, measured in transmission experiments on thin and thick samples can be written[7] as $T=g\Gamma_N\Gamma^p$ where p lies between 0 and 1. Both S and T can be represented as lines on a plot of neutron width, Γ_N, against total width, Γ. If the experimental points were precise and correct, the curves so obtained would pass through the same point for one value of g but not for the other. In practice, these curves do not do so but define an area of intersection. Hence, one cannot determine the value of g unambiguously, but one can assign relative probabilities to the two possible solutions. This was done by a least squares method[7,10] coded for an IBM 650 computer. For platinum only one isotope, Pt^{195}, has two possible values for g, viz., $\frac{1}{4}$ or $\frac{3}{4}$; all the others have $g=1$. The more probable value of g for a Pt^{195} resonance is given by the lower value of $\chi_{\min}^2$, the sum of the squares of the weighted deviations of the experimental values of the neutron width from the mean.

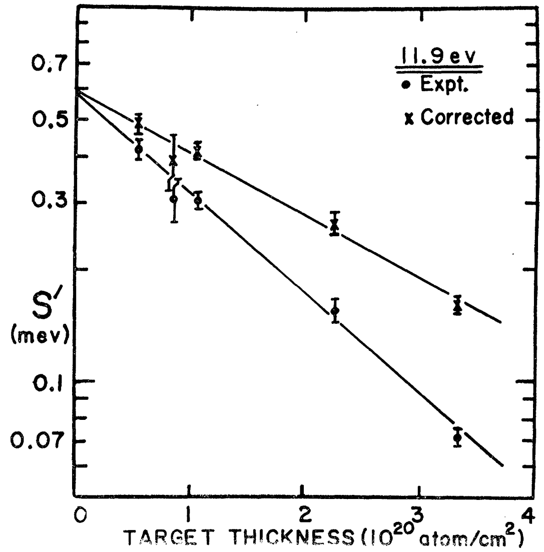

FIG. 1. Values of S' for the 11.9-ev resonance in Pt^{195} isotope as a function of target thickness.

Values for transmission areas were obtained from the literature, where possible, and from unpublished data. Details are given in the next section. One series of transmission measurements were made using the General Electric 100-Mev betatron as a pulsed neutron source.[11] A bank of BF_3 counters was located at a flight path of 7.8 meters, the data being taken on a 200-channel analyzer with 0.625 μsec timing channels. The nominal resolution was 80 nsec/m. (1 nsec$\equiv 10^{-9}$ sec.) Thick-sample areas were obtained for the 11.9-ev and 19.6-ev resonances, there being no point in going to any higher energy since the resolution was not good enough with this short flight path.

RESULTS

Scattering

The values for S' and S obtained for each target thickness for the resonances at 11.9, 19.6, 68, and 96 ev are listed in Table I. The errors in S' are standard deviations and include the statistical uncertainty due to the finite number of counts recorded, the target thickness, etc.; those for S include an estimate of the error incurred in the extrapolation process. This was rather difficult to evaluate but was done graphically taking into account the errors in S' and the possible different values of S that could be obtained by altering the extrapolation within reasonable limits. The errors are probably greater than would be allotted if a least squares fit were made to a straight-line extrapolation, but were left this way since no allowance was made for any systematic errors in the measurement. Previous measurements[6,7,12] have shown that this method of

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TABLE I. Values for S' (proportional to the scattering area divided by the target thickness) and S (the extrapolated value of S') for the 11.9-, 19.6-, 68-, and 96-ev resonances in platinum. The 68-ev resonance is assumed to be in Pt^{195} (see text).

11.9-ev resonance: $S=0.59\pm0.09$ mev						
Sample thickness (10^{20} atom/cm^2)	3.34	2.27	1.07	0.850	0.537	
S' (mev)	0.0716	0.154	0.303	0.305	0.415	
Error in S' (%)	5	7	5	13	6	
19.6-ev resonance: $S=0.36\pm0.06$ mev						
Sample thickness (10^{20} atom/cm^2)	3.34	2.27	1.07	0.850	0.537	
S' (mev)	0.084	0.106	0.161	0.214	0.239	
Error in S' (%)	15	15	15	17	20	
68-ev resonance (see text): $S=41\pm3$ mev						
Sample thickness (10^{20} atom/cm^2)	2.27	1.07	0.537	0.312		
S' (mev)	23.4	29.2	35.0	37.7		
Error in S' (%)	9	10	12	12		
96-ev resonance: $S=360\pm36$ mev						
Sample thickness (10^{20} atom/cm^2)	0.484	0.230	0.230	0.115	0.115	0.0668
S' (mev)	246	282	256	313	288	380
Error in S' (%)	15	16	10	15	15	20
Flight path (m)	12	12	19	12	19	12
Combined S' (mev)		263 (8.5%)		300 (10%)		

evaluating S leads to results that are consistent with values of S derived from resonance parameters, where they are known, and also with other experiments.

Although values for S' and S are given for the 68-ev resonance these should be accepted with caution since there have been reports[2,13] that this resonance is, in fact, two unresolved resonances. The value for the target thickness has been calculated under the assumption that there was only one resonance, that being in Pt^{195} as reported previously.[14] If higher resolution experiments show that there are really two resonances and that the second one has appreciable scattering, the value for S given in the Table I will be wrong. However, it should be noted that since S is proportional to Γ_N^2/Γ, and that a small resonance will have $\Gamma\gg\Gamma_N$, there will not be an appreciable correction to S if the second resonance is much smaller than the known one.

TABLE II. Transmission areas used in the determination of the resonance parameters. The figures in parentheses in column 4 are the percentage standard deviations of the reported areas. Column 5 is a code number for easy reference to particular measurements. Column 6 gives the reference number of the source of the information; values marked * were measured by the author for this report.

Resonance energy (ev)	Platinum isotope	Sample thickness (10^{20} atom/cm^2)	Area (ev)	Code	Source ref.
11.9	195	0.538	0.131 (7)	*T*1	15
		3.278	0.454 (3.5)	*T*2	18
		3.40	0.49 (6)	*T*3	18
		5.52	0.702 (4)	*T*4	15
		16.65	1.032 (2)	*T*5	18
		0.806	0.163 (5)	*T*6	16
		16.85	1.08 (5)	*T*7	*
19.6	195	1.64	0.197 (11)	*T*1	15
		23.1	0.924 (4)	*T*2	15
		16.65	0.676 (3)	*T*3	18
		3.278	0.256 (5)	*T*4	18
		3.40	0.26 (23)	*T*5	18
		0.806	0.0784 (8)	*T*6	16
		16.85	0.692 (6)	*T*7	*
96	198	0.185	0.38 (50)	*T*1	18
		3.558	2.30 (8)	*T*2	18
		22.05	6.35 (5)	*T*3	18
		0.159	0.271 (12)	*T*4	16
		0.172	0.303 (15)	*T*5	16
		0.634	0.886 (6)	*T*6	16
		2.243	2.13 (4)	*T*8	16
		0.479	0.715 (5)	*T*9	17
		7.180	3.310 (4)	*T*11	17

Transmission

The only published transmission areas for the low-energy platinum resonances are those of Stolovy and Harvey.[15] However, additional unpublished results have been obtained from Harvey,[16] Corge,[17] and Chrien.[18] These are listed in Table II. The figures in brackets in column 4 are the reported percentage standard deviations of the measurements.

When the transmission values were plotted on the graph of Γ_N vs Γ, it appeared that some of the measurements were not consistent with the others. To get a consistent set the process used by Crowe, Cohen, and DuMond[10] mentioned earlier was utilized. This process yields a value of $\chi_{\min}^2$ which is proportional to the sum of the squares of the weighted deviations of the input data from their mean. By taking the lines in groups, it is possible to spot any one that is not consistent since its inclusion will give a greatly increased value of $\chi_{\min}^2$.

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[18] R. E. Chrien (private communication, 1959).

TABLE III. Best values of the parameters for the 11.9-, 19.6-, and 96-ev resonances. The preferred values of g are in boldface.

Resonance energy (ev)	Platinum isotope	g value	Γ_N (mev)	Γ_γ (mev)	No. of expts.	$\chi_{\min}^2$
11.9	195	$\frac{1}{4}$ ($J=0$)	25.9± 0.9	126± 8	6	24.7
		$\frac{3}{4}$ ($J=1$)	10.0± 0.3	112± 7	6	3.3
19.6	195	$\frac{1}{4}$ ($J=0$)	17.0± 0.7	133±11	4	8.5
		$\frac{3}{4}$ ($J=1$)	6.9± 0.3	100± 8	4	0.8
96	198	1 ($J=\frac{1}{2}$)	452 ±13	105±38	7	1.4

The particular experimental values that were rejected and the reasons are given in the next sections that deal with the individual resonances.

11.9-ev Resonance

There are 7 values of transmission areas listed in Table II for this resonance of which the last one, $T7$, is the one measured in this experiment. However, the target thickness used was nearly the same as that in $T5$ and the areas also agreed well. Since $T5$ has a smaller reported error, it was used in the combination and $T7$ merely used for confirmation. This leaves 6 lines to appear on Fig. 2. By inspection it would appear that the agreement is good, with the possible exception of $T4$. To check this the values were taken in the following groups: (a) $T1$, $T2$, $T3$, $T5$, and $T6$; (b) $T1$, $T2$, $T4$, $T5$, and $T6$; (c) $T1$, $T2$, $T3$, $T4$, and $T5$. The values for $\chi^2_{\min}$ obtained for these combinations were (a) 3.16, (b) 22.4, (c) 18.8. Since there are the same number of experiments in each combination these numbers can be compared directly, showing that the probability that either set (b) or (c) is correct is much less than that set (a) is the correct one. Hence, the final set that was taken to determine the best parameters was set (a) plus the value of S. This combination gave the results listed in Table III. It can be seen that $g=\frac{3}{4}$ (corresponding to $J=1$) has a $\chi_{\min}^2$ that is much smaller than that for $g=\frac{1}{4}$ and so is to be preferred. It is interesting to note that if all the transmission experiments are used, i.e., $T4$ is included, the neutron and radiation widths become 10.1±0.3 mev and 118±7 mev so that the values are still within the experimental error.

19.6-ev Resonance

Of the seven T values in Table II, $T4$ and $T5$ have almost the same target thickness and good agreement in the measured area. Hence, $T5$ was not used since its error was far greater than that of $T4$. Similarly the value of T measured in this experiment, $T7$, agreed well with $T3$ so the latter was used since it had the smaller error. This leaves 5 values for the transmission area, viz., $T1$, $T2$, $T3$, $T4$, and $T6$ as shown in Fig. 3. $T1$ and $T2$ are in major disagreement with these other values; it was really to decide between the groups ($T1$, $T2$) and ($T3$, $T4$, $T5$, $T6$) that a thick-sample area was measured for this report. Since the value that

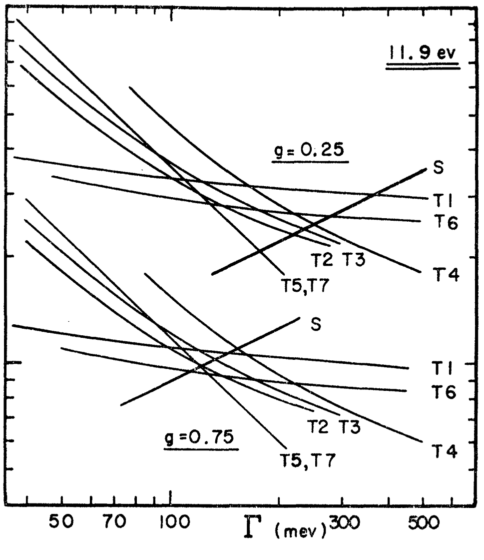

FIG. 2. Plot of Γ_N vs Γ for the 11.9-ev resonance in Pt^{195} isotope.

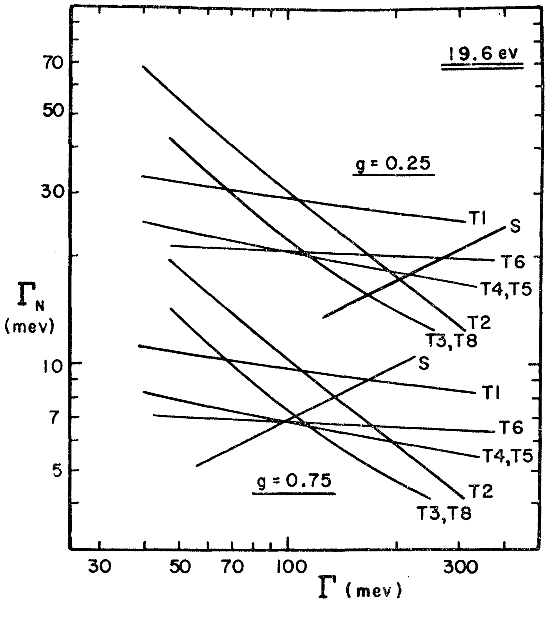

FIG. 3. Plot of Γ_N vs Γ for the 19.6-ev resonance in Pt^{195} isotope.

resulted, namely $T7$ agrees with $T3$ rather than with $T2$ (with an allowance made for the slightly different target thicknesses) it was decided on this basis not to use the values for $T1$ and $T2$ in the combination with S to find the parameters. Table III gives the values of these parameters using the set $T3$, $T4$, $T6$, and S. As a matter of interest the parameters using $T1$ and $T2$ as well are $\Gamma_N = 7.2 \pm 0.3$ mev, $\Gamma_\gamma = 111 \pm 8$ mev which do not differ greatly.

This resonance also has the preferred value of g equal to $\frac{3}{4}$. This is the value that was determined from the capture γ-ray experiments[1–5] and agrees with the preliminary results given by Harvey[19] using a combination of scattering and transmission experiments similar to the method used here.

68-ev Resonance

Although values for S and S' have been given for this resonance and transmission measurements were available, they were not combined to get the resonance parameters since it appears very likely that this is really two unresolved resonances.[2,13] If the second resonance is small, the value of S can be corrected for it, but it does not appear possible to correct the values of T. This is because T is proportional to $\Gamma_N \Gamma^p$ and a small resonance will have an appreciable Γ due to the approximately constant radiation width. The values of T measured so far are for the sum of the two resonances. Any resonance parameters that were derived using these values of T would almost certainly be wrong. If better resolution measurements of T for the 68 ev in Pt^{195} become available, these could be combined with the corrected value of S. This procedure was used by the author[7] for the 100.8-ev level in W^{183} with satisfactory results.

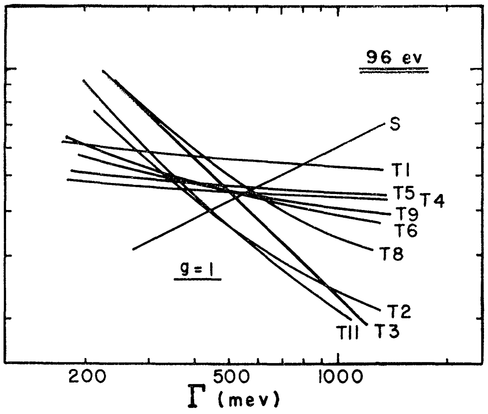

FIG. 4. Plot of Γ_N vs Γ for the 96-ev resonance in Pt^{198} isotope.

96-ev Resonance

There were 9 values of T available for this resonance as shown in Table II. $T1$ had a very large error and would not have affected the combination even if it had been included. Figure 4 indicates that $T2$ and $T11$ are in disagreement with all the others so the combination used was $T3$, $T4$, $T5$, $T6$, $T8$, $T9$, and S. Since this is a resonance in the isotope Pt^{198}, $g = 1$. At this high energy the scattering measurements lose some of their value since the neutron width is over 80% of the total width of the resonance. However, there is still some utility in these measurements. To illustrate this, the 6 transmission areas were combined to get values of the level widths. These were as follows:

$$\Gamma_N = 461 \pm 27 \text{ mev}, \quad \Gamma_\gamma = 71 \pm 88 \text{ mev}.$$

It can be seen that the error on the radiation width is so large that the value has little meaning. However, by the addition of a scattering measurement of 10% standard deviation the level widths are now:

$$\Gamma_N = 452 \pm 13 \text{ mev}, \quad \Gamma_\gamma = 105 \pm 38 \text{ mev}.$$

These values are now of some use since the error on the radiation width is less than the width. This demonstrates that the technique of combining only transmission measurements to get resonance parameters leads to large uncertainties, at least until the energy is high enough so that the radiation width can be neglected in comparison with the neutron width.

ACKNOWLEDGMENTS

I wish to thank Dr. J. A. Harvey, of Oak Ridge National Laboratory, Dr. R. E. Chrien, of Brookhaven National Laboratory, and Dr. C. Corge, of the Centre D'Études Nucléaires de Saclay, for sending me their unpublished transmission data. At Rensselaer Polytechnic Institute I should like to thank Mr. Sherman Tsao for programming the least squares calculation on the IBM 650 and Mrs. Janet Bykoski for help with the calculations for the transmission experiments.

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[19] J. A. Harvey, Bull. Am. Phys. Soc. 4, 473 (1959).