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Ugo Amaldi, Jr., Gloria Campos Venuti, Giorgio Cortellessa, Gabriele Fronterotta, Armando Reale, Paolo Salvadori

The (e, e'p) reaction in the S^{32} nucleus

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Fisica. — *The* $(e , e' p)$ *reaction in the* S^{32} *nucleus* (*). Nota di UGO AMALDI, JR. (**), GLORIA CAMPOS VENUTI (**), GIORGIO CORTELLESSA (**), GABRIELE FRONTEROTTA (**), ARMANDO REALE (**) e PAOLO SALVADORI (**), presentata (***) dal Corrisp. M. AGENO.

In a previous paper [1] we have discussed the relative merits of the $(p , 2 p)$ and $(e , e' p)$ reaction when used to determine the binding energy of inner protons in nuclei. From this discussion there arose an interest in performing $(e , e' p)$ experiment in light nuclei even if the energy resolution is actually poorer than that currently obtained with $(p , 2 p)$ reactions. This is because even in light nuclei exist structures at high values of the binding energy with a large energy width. In intermediate nuclei we have already pointed out the existence, so far unknown, of deeply bound protons [2]. This feature has been seen in Al^{27} and there immediately appeared the necessity of extending the investigation to higher mass numbers. One reason is that aluminum is a deformed nucleus and it could be doubted whether such high binding energies are connected with the deformation.

A second, more general, reason is that the $(e , e' p)$ measurement can be extended to heavier nuclei partly avoiding the difficulty of the strong proton absorption that limits the use of the $(p , 2 p)$ reaction to the exploration of light nuclei levels and of the external levels of intermediate nuclei.

The experimental apparatus is that used for the Be^9 measurement except that the proton telescope has a solid angle of 0.16 sr instead of $\simeq 1$ sr. This difference in solid angles is necessary because the increase in mass numbers, and thus in atomic numbers, involves a much higher electromagnetic background in the telescope. The cross sections for the electromagnetic processes depend roughly upon Z^2 while the true counting rate is linear in Z. The background is so high that the scintillation counters of the proton telescope are heavily loaded and the pulse height distribution is badly distorted. Because of the inherent instability of the intensity of the machine from pulse to pulse it is not possible merely to reduce the average intensity of the machine because it could happen that some very high intensity pulse could block temporarily the counter telescope. In order to sure that this event would not happen we were compelled to reduce the solid angle so that even the worse fluctuation of the machine intensity could not block the counting chain.

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(**) Laboratori di Fisica dell'Istituto Superiore di Sanità, Roma.
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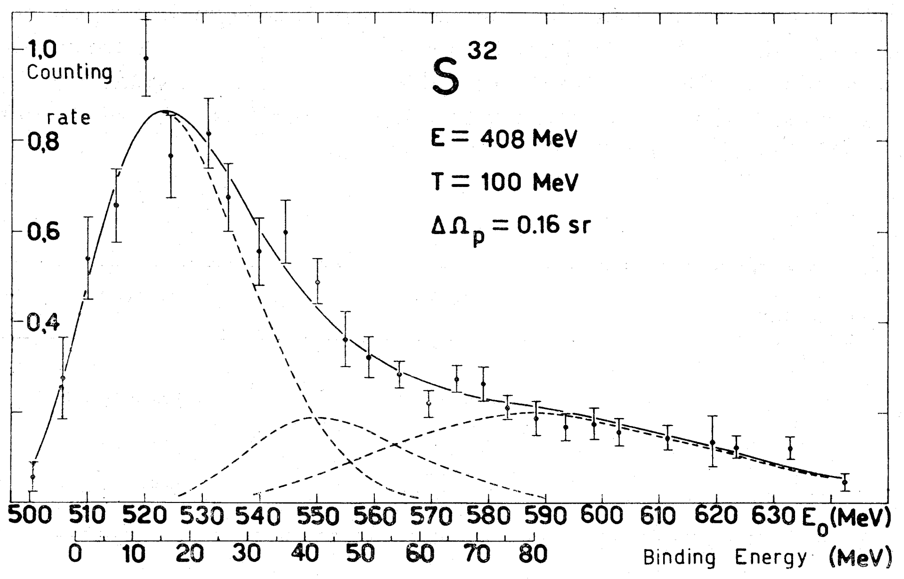

Fig. 1.

Other features of the experiment are the same already described [1]. The S^{32} results are presented in fig. 1. The experimental points are plotted as counting rate normalized to a fixed number of incoming electrons. The fig. also shows the result of the interpolation, through the experimental points, of a sum of three maxwellian distributions whose parameters are reported in Table I.

TABLE I.

h (counting rate)	σ (MeV)	x_0 (MeV)
0.84 ± 0.13	27.5 ± 3	523.2 ± 2.2
0.23 ± 0.08	31 ± 11	553 ± 7
0.17 ± 0.04	59 ± 17	593 ± 9

We may call attention to the fact that the interpolation assumes the following form of the maxwellian distribution:

$$y = h \frac{(x - x_0 + \sigma)^2}{2} \exp\left[1 - \frac{(x - x_0 + \sigma)^2}{2}\right].$$

The choice of this function has been already justified [1] and the statistical interpolation method has been described elsewhere [3].

It is worth mentioning that the addition of a straight line to the three maxwellian distributions leads to the results of Table II, which are not statistically different from the results of Table I because the significance level of the interpolation whose parameters are in Table I is 52% where in the case of Table II it is 35%.

TABLE II.

h (counting rate)	σ (MeV)	x_0 (MeV)
0.86 ± 0.13	27.5 ± 3	522.9 ± 2.2
0.19 ± 0.07	29 ± 11	551 ± 7
0.19 ± 0.04	60 ± 17	588 ± 9

A four maxwellian fit either has a significance level of less than 1% or degenerates into one of the above fits with two of the curves coincident. Any attempt to fit the data with gaussian curves leads to significance levels of less than 1%.

The necessity of using a maxwellian fit has been already discussed in our previous paper [1] and is related to the so called "radiation tail".

Some conclusions can be drawn from the two tables.

Taking into account the position of the zero on the energy scale it is possible to build Table III, averaging the values of the two fits for the binding energy of the various states, according to a shell-model attribution. The average is fully justified, the values being well within the statistical error.

TABLE III.

Possible attribution	Binding Energy (MeV)
$2s$–$1d$	15.0 ± 2.2
$1p$	44 ± 7
$1s$	72 ± 9

The conclusions are the following:

a) the high value of the binding energy already found for the Al^{27} is fully confirmed also for S^{32}, spherical nucleus, and is therefore not due to the deformation of the aluminum nucleus;

b) already looking at fig. 1 it is seen that the areas under the peaks are definitely not in agreement with a naïve shell model picture of the reaction because these would have been about in the ratio 8 : 6 : 2 i.e. in the ratio of the number of protons in the $2s$—$1d$: $1p$: $1s$ shell.

It is beyond the scope of this short paper to attempt a theory of such high binding energies and of the ratios of the fitted peaks. But we can at least make some observations and indicate the lines for further developments.

The measurement of binding energies does not yet contain an experimental confirmation that the energy missing in the energy balance i.e. the difference between the incoming energy and the sum of the energies of the outgoing particles is all spent as binding energy of the proton.

The inner peak in the S^{32} spectrum has a width corresponding to a lifetime (according to the uncertainty principle) of less then the transit time of the particle involved in the reaction. This has been already pointed out by our group [4] and leads to the conclusion that the reaction cannot be described as an ejection of a proton struck by the incoming electron, with the rest of the nucleus spectator of the reaction, and a subsequent decay of the final state of the direct reaction. These two steps cannot be separated because, evidently, the final state is decaying during the reaction time. Any attempt to account for the missing energy in the energy balance using a static calculation of binding energy may be wrong if it is not justified on some physical ground the spectator nucleus assumption. For this reason we are now pursuing angular distribution measurement as a test that the reaction could still be described as a direct reaction even if the nucleus is actually decaying in a short time.

The angular distribution of protons should show the features calculated using the impulse approximation. Were this not the case we should seriously reconsider the meaning of the missing energy in the reaction.

As far as the conclusion *b*) is concerned, it is very probable that in an intermediate nucleus also the static concept of inner shells becomes meaningless. If this is the case, the attribution of the two more bound contributions of our fit to the $1s$ and $1p$ shells has no justification. Nevertheless we think that the important result is that there exist protons that require such a high energy to be removed from the nucleus. Also this point must, of course, be confirmed by an experimental demonstration that the measured missing energy is equal, or almost equal, to the binding energy.

It is finally worth noting that the static calculation does not, nevertheless, disagree with binding energies higher than those predicted by the naïve shell model. Recently [5] it has been shown that the introduction of a non-local potential in the Hartree-Fock type calculation leads immediately to higher values of the static binding energies.

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RIASSUNTO. — *La reazione* $(e, e' p)$ *sul nucleo di zolfo*. – Con l'apparato sperimentale utilizzato nel caso del Be^9, ma con un diverso angolo solido di rivelazione dei protoni, sono state studiate le energie di legame dei protoni dello S^{32} mediante la reazione $(e, e' p)$. Sono riportati i risultati ottenuti, insieme a una discussione sulle interpolazioni dei dati sperimentali utilizzate: è da notare che per quanto riguarda i livelli $1s$ e $1p$ è la prima volta che essi vengono sperimentalmente determinati in quanto, come è noto, la reazione $(p, 2p)$ dà risultati solo sui livelli più esterni nei nuclei medi e pesanti. Infine, in seguito ad alcune considerazioni sui tempi di decadimento dei livelli connessi alle larghezze sperimentali trovate, viene mostrata la necessità di procedere alla misura delle distribuzioni angolari dei protoni emessi, per saggiare definitivamente la validità dell'approssimazione del nucleo spettatore e l'identificazione dell'energia mancante con l'energia di legame.