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EFFECTIVE INTERACTION AND THE REACTIONS ^{7}Li(p,p')^{7}Li(478 keV) AND ^{7}Li(p,n)^{7}Be(431 keV)†

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The total cross sections for the reactions ^{7}Li(p,p')^{7}Li(478 keV) and ^{7}Li(p,n)^{7}Be(431 keV) have been measured for proton energies between 23 and 52 MeV and compared with the predictions of a microscopic model of the reaction. The spin-flip, isospin-flip part of the effective interaction is found to be essentially independent of energy, whereas the pure central part appears to decrease with increasing energy.

In the distorted-wave theory of inelastic scattering the transition amplitude has the form[1,2]

$$T_{fi}=\int\chi_f^{(-)*}(\vec{r})\langle\Psi_f|V_{\text{eff}}|\Psi_i\rangle\chi_i^{(+)}(\vec{r})d\vec{r}.$$

The χ_i and χ_f are distorted waves describing the elastic process and are generated from optical-model parameters which fit the elastic scattering from the target nucleus. This expression neglects particle exchange.

If one wishes to obtain detailed spectroscopic information, one must use a microscopic model in which Ψ_f and Ψ_i are shell model states and V_{eff} is the effective interaction causing the transition from Ψ_i to Ψ_f. Except at energies well above 100 MeV, where one can with good accuracy set V_{eff} equal to the free nucleon-nucleon interaction,[3] there is no simple way to determine V_{eff} from external information.[2,4] For this reason it is difficult to isolate properties of the nuclear wave function from uncertainties in V_{eff}. Several authors[2,4,5] have suggested that in this situation one should attempt to determine V_{eff} from a comparison of experiments with theory in cases where the wave functions are known. The present Letter describes a measurement of V_{eff} and an attempt to make the first determination of its energy dependence.

The reactions

$$^7\text{Li}+p\rightarrow{}^7\text{Li}(478\text{ keV})+p,$$

$$^7\text{Li}+p\rightarrow{}^7\text{Be}(431\text{ keV})+n,$$

leading to the mirror first excited states of ^{7}Li and ^{7}Be, are well suited for investigations of V_{eff}. These states have $J^\pi=\frac{1}{2}^-$; so the angular distributions of the de-excitation gamma rays are isotropic in the rest frame of the recoiling nucleus. In addition, these states are the highest energy particle-stable states; so they are not fed with appreciable probability by gamma-ray transitions from above. For these reasons a measurement of the intensity of the de-excitation gamma ray at a single angle is a measure of the total cross section for the reactions.[6] This method enables one to measure the total cross section of a (p,n) reaction in a case for which standard techniques would not have sufficiently high resolution.

Protons from the Michigan State University sector-focused cyclotron bombarded a 59 mg/cm^2 thick, self-supporting target rolled from natural lithium metal. The gamma radiation was detected in a 3-cm^3 Ge(Li) detector which was placed at the largest possible angle (166°) from the beam to reduce the Doppler broadening of the peaks and the neutron background. At each energy, spectra were recorded both with the target in the beam and with the target removed to permit the subtraction of backgrounds which did not originate in the target. Figure 1 shows spectra taken at 25 and 52 MeV.

The cross sections obtained after correction for the relative detection efficiency of the 431- and 478-keV gamma rays and normalization to a total ^{7}Li(p,p')^{7}Li(478 keV) cross section measured at 24.4 MeV[7] are shown in Fig. 2.

In order to relate these results to an effective interaction, V_{eff} is assumed to have the form[1,2,5]

$$V_{\text{eff}}=\sum_i t_i,$$

where t_i is the scattering amplitude from the

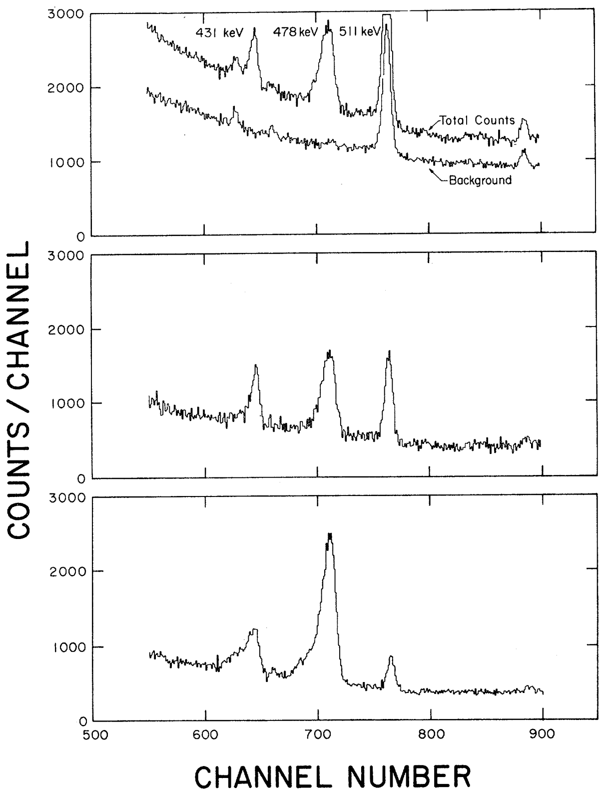

FIG. 1. Gamma-ray spectra taken at 25 (bottom) and 52 (middle and top) MeV. The peaks at 431 and 478 keV arise from the reactions ^{7}Li(p,p'), ^{7}Li(478 keV), and ^{7}Li(p,n)^{7}Be(431 keV), respectively, while the 511-keV peak arises from β^+ annihilation. Other peaks appear also in the background not associated with the target and can be traced to proton-induced reactions in the beam pipe and Faraday cup. The detector resolution was about 5 keV, but the 431- and 478-keV peaks are Doppler broadened.

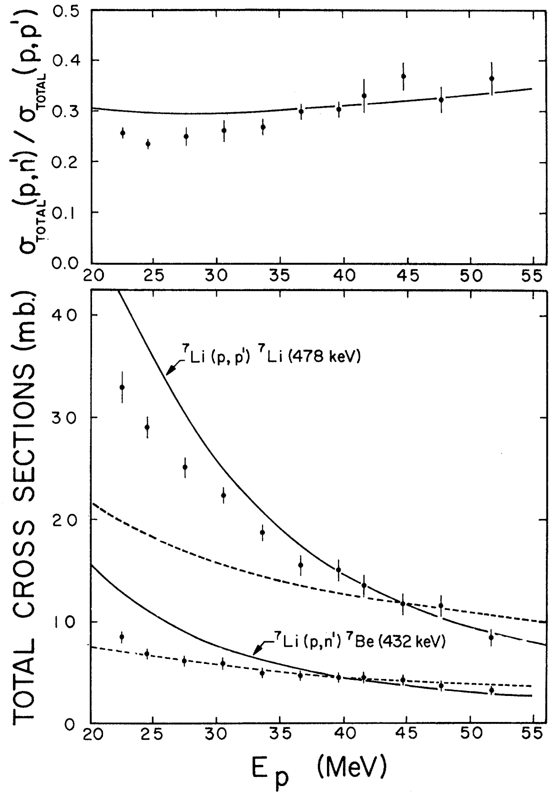

FIG. 2. Total cross sections for the reactions ^{7}Li(p, p')^{7}Li(478 keV) and ^{7}Li(p,n)^{7}Be(431 keV). The top graph shows the ratios of these cross sections with their statistical errors and the lower graph shows the cross sections normalized to Ref. 7 plotted with their total errors (exclusive of normalization errors). The dashed and solid curves are theoretical predictions discussed in the text.

ith target nucleon and

$$t_i = V_{00} + V_{10}\vec{\sigma}\cdot\vec{\sigma}_P + V_{01}\vec{\tau}_i\cdot\vec{\tau}_P + V_{11}(\vec{\sigma}_i\cdot\vec{\sigma}_P)(\vec{\tau}_i\cdot\vec{\tau}_P).$$

The operators $\vec{\sigma}_P$ and $\vec{\sigma}_i$ are the Pauli spin operators for the projectile and struck particle, respectively, and the τ's are the analogous operators for the isospin. In this parametrization of $V_{\rm eff}$ the subscripts on the V_{ST} are the transferred spin S and isospin T. McManus et al.[5,8] have obtained the V_{ST} from a fit to the Hamada-Johnson nucleon-nucleon potential. In this case the interactions are local and complex, and have a Yukawan radial dependence. Each V_{ST} has a different strength and range, both of which are energy dependent. Other authors[2] have fitted inelastic scattering data by varying the strength of a real, Yukawan potential with a range of 1.0 F.

The selection rules allow eight amplitudes [labeled by (L, S, J, T): the transferred orbital, spin, and total angular momentum, and the transferred isospin] to contribute to the (p,p') cross section while four contribute to the (p,n) reaction. As a first step we calculated all of these terms in the zero-range plane-wave impulse approximation using the t_i of McManus et al.[5,8] Harmonic-oscillator wavefunctions with a length parameter $b = 1.72$ F[9] were used in the L-S coupling limit. The results are shown as solid curves in Fig. 2. Since plane-wave calculations are not expected to predict the magnitudes of the cross sections correctly, the curves have been normalized to the (p,p') cross section at 44.7 MeV. These curves indicate that both the ratio of the cross sections and the energy dependence are given approximately by the interactions of McManus.

These calculations fit the data somewhat better than one might expect considering the crudeness of the model. To determine whether this is fortuitous we have made some preliminary distorted-wave calculations using the same wave functions and the finite-range McManus interaction. These calculations give cross sections that are roughly correct in magnitude. They agree with the plane-wave calculation in the identification of which terms are the most important contributors to the cross sections and in the energy dependence of the cross sections. However, the ratio of the (p,n) to the (p,p') cross sections is about 0.6, roughly twice the experimental value. This effect can be traced to the fact that the $(LSJT)=(2020)$ amplitude is smaller relative to other amplitudes in the distorted-wave calculations. Since this amplitude is more important in the (p,p') reaction, it appears that the inclusion of a quadrupole enhancement which might arise from core polarization effects[10] would decrease the discrepancy.

Both the plane- and distorted-wave calculations show that a single V_{ST} dominates the cross sections. In the (p,p') reaction V_{00} contributes 70 % of the cross section while V_{11} accounts for 90 % of the cross section in the (p,n) reaction. Although the percentages presumably depend upon the choice of wave function, we may regard the two processes as rough measures of V_{00} and V_{11}, respectively. Under the assumption that V_{00} and V_{11} are real, independent of energy, and have a Yukawan shape with a range of 1.0 F, distorted-wave calculations give the dashed curves shown in Fig. 2. The strengths of the potentials required to fit the total cross sections at 44.7 MeV are $V_{00}=90$ MeV and $V_{11}=15$ MeV. A comparison of the results of the calculation with the data shows that V_{00} should be taken to be energy dependent. At 25 MeV a strength of 113 MeV would fit the data. The shape of the angular distribution calculated with $V_{00}=113$ MeV at 25 MeV is in fair agreement with the data of Crawley and Austin[7] at 24.4 MeV. There is no evidence for an energy dependence of V_{11}.

Other analyses[2,10] of inelastic scattering data have given values of V_{00} between 100 and 200 MeV depending upon whether or not core polarization was taken into account. A value of V_{11} of 7 MeV (assumed range of 1.4 F) has been derived from measurements of the $^{14}C(p,n)$ cross sections near 14 MeV.[11] An analysis of inelastic scattering from ^{208}Pb gives a value of 10 MeV.[10]

We are continuing the distorted wave analysis with an emphasis on the use of form factors which account for the core polarization of ^{7}Li.[10]

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Note added in proof.—The value of V_{11} given in this paper is in good agreement with an analysis of measurements of the total cross section for the reaction $^{6}Li(p,p')^{6}Li$ to the $T=1$ second excited state.[12] In this case V_{11} is the only term which contributes to the cross section.

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X-RAY EMISSION FROM Cen XR-2*

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In a recent communication, Chodil et al.[1] have reported the possible existence of a variable source of x rays in Centaurus, which they have tentatively identified with that previously observed and reported by Harries et al.[2]

Chodil et al.[1] suggest that the mechanism for x-ray emission in the source they designate as Cen XR-2 is thermal bremsstrahlung at a temperature of 1.5 keV. They further suggest that Cen XR-2 is much like Sco X-1—but at a lower temperature. We do not subscribe to the hypothesis that the extar Sco X-1 is a thermal bremsstrahlung source,[3-5] but we find it of more than passing interest, within the context of the thin-hot-plasma model, to relate the possible behavior of Cen XR-2 in the visible portion of the spectrum to the reported variation of its x-ray luminosity.

To begin with, we make the following assumptions:

(a) The x-ray luminosity and spectrum of Sco X-1 are relatively constant, and the discrepancy between the intensity of Sco X-1, measured by Chodil et al. in May 1967, as compared with their previous measurements,[6] is purely instrumental; the import of this assumption is that it establishes a common reference point between various observers and their several experimental methods.

(b) The source observed by Harries et al.[2] in April 1967 and referred to as "Crux" is indeed identical with that observed by Chodil et al.[1] about a month later.

(c) On noting assumption (a), we take the observed change in x-ray luminosity of Cen XR-2 between April and May 1967 to be real, but assume that the temperature of Cen XR-2 did not change significantly. Note that the estimates of the spectrum reported by Harries et al., compared with the data in Ref. 1, strongly support this assumption.

On taking into account that Grader et al.[7] failed to detect Cen XR-2 in October 1965, we obtain the following behavior of the relative x-ray luminosity of this source between October 1965 and May 1967. The luminosity had to increase by a factor of at least 50 within a time scale of, say, 5×10^7 sec (October 1965 to April 1967); this seems to be followed by a fivefold decrease in luminosity within, say, 2.5×10^6 sec.

Assume now that the mass of the radiating plasma is essentially constant and so is its distance from the solar system. Then, as is well known, the total power radiated by the source is proportional to $T^{1/2}n_e$, where T and n_e are the electron temperature and density, respectively. (Note that because of the constant-mass assumption, the luminosity is not proportional to n_e^2.)

Consider first the phase between October 1965 and April 1967. If we assume that the intensity variation was associated with an increase in the electron temperature, the mass and size of the extar remaining constant, then it follows that in October 1965 the optical counterpart of Cen XR-2 should have been brighter than about 12th magnitude. This conclusion rests on the observation that while the total output of a thin thermal bremsstrahlung source in the high-energy region is proportional to $T^{1/2}\times\exp(-h\nu/kT)$, the output at frequencies much smaller than kT/h, other things being equal, is proportional to $T^{1/2}$. Thus, contrary to the conclusion of Chodil et al.,[1] granting the thermal bremsstrahlung model, it may be possible to find a bright visual object at the position of the subject extar on plates of the area made during October 1965. An absence of such an object would decidedly discount the possibility that the early variability of Cen XR-2 was associated with related temperature fluctuations. On the other hand, a discovery of such an object would not necessarily serve as a positive proof of the tenability of the thermal bremsstrahlung hypothesis, because similar effects can occur as a result of magnetic field intensity variations in a synchrotron model for ex-