The experimental data are compared to calculations in the self-consistent Hartree-Fock model with various Skyrme forces and Moszkowski modified delta interaction. It is found that for description of deep levels more nonlocality of the internucleon interaction (corresponding to the effective mass m* of nucleon m*/m $\approx$ 0.5) is required then for the description of levels near the Fermi surface.

REFERENCES

1. *Vorobyov A.A. et al.*//Yadernaya Fiz.,1995. Vol.58, issue 11, 1923.
2. *Vorobyov A.A. et al.* Preprint PNPI-1875, Gatchina, 1993, 43 p.

STUDY OF MESIC ATOMS AT THE PROTON BEAM OF THE MOSCOW MESON FACTORY (MMF) WITH A TWO-CRYSTAL DIFFRACTION SPECTROMETER (PROJECT "MADIS")

K. E. Kiryanov, A. V. Kravtsov, P. A. Kravtsov, Yu. G. Kudenko[1)], O. E. Lapin, V. M. Lobashev[1)], V. I. Marushenko, A. F. Mezentsev, A. A. Petrunin, V. A. Churkin

[1)] *Institute for Nuclear Research, RAS*

1. Measurement of the energy shift and width of 1s-level of the pionic hydrogen atom, caused by the strong πN-interaction and derivation of πN scattering lengths

Pion-nucleon scattering lengths are usually determined from the phase-shift analysis of the low-energy πN-scattering data using dispersion relations and the extrapolation to zero energy. Such an indirect method leads to ambiguous results due to the experimental data dispersion as well as because of the difference in the phase-shift analyses results [1].

There exists however another way to obtain the πN-scattering lengths, namely the study of the $(np-1s)$ transitions in the pionic hydrogen atom. In this case one should measure the energy and width of the transition in pionic hydrogen. Experimental transition energy determines the shift ϵ_{1s} of the 1s-level, caused by the strong interaction, while the width of the transition is almost equal to the width of the 1s-level Γ_{1s}, caused by the pion absorption by the proton. The shift and the width of the pionic hydrogen 1s-level can be expressed by a Deser formulae [2] via πN scattering lengths a_1 (isospin $T=1/2$) and a_3 (isospin $T=3/2$):

$$\epsilon_{1s} = -\frac{4E}{3R}(2a_1+a_3) \quad (1)$$

$$\Gamma_{1s} = \frac{16QE}{9R}(1+1/P)(a_3-a_1)^2, \quad (2)$$

where E is the binding energy of the 1s-level, R is the pionic Bohr radius, Q is a kinematic factor and P is the Panofsky ratio.

The scattering lengths a_1 and a_3 thus obtained do not contain theoretic uncertainties so the accuracy is determined by the experimental errors in the energy shift and width. To obtain the values a_1 and a_3 with an accuracy (1-3)% one should measure the 1s-level shift

($\epsilon_{1s} \sim 7\ eV$) with an accuracy 0.05 eV and the width ($\Gamma_{1s} \sim 0.9\ eV$) with an accuracy 0.03 eV.

Such high accuracies can be reached only with crystal diffraction spectrometers. The first proposal to use a focusing crystal diffraction spectrometers for study of pionic hydrogen and deuterium atoms was made at LNPI in 1977 [3]. Since then a number of measurements using such a technique were performed in the USA and in Switzerland. The results of the recent measurement [4] allow one to obtain the scattering lengths a_1 and a_3 with the relative accuracies 4% and 14% respectively:

$$a_1 = 0.260 \pm 0.010\ fm, \qquad a_3 = -0.147 \pm 0.020\ fm$$

The s-wave πN scattering amplitude can be written as

$$f_{\pi N} = b_0 + b_1(\vec{t} \cdot \vec{\tau}),$$

where $b_0 = (a_1 + 2a_3)/3$ is the isoscalar πN scattering length, $b_1 = (a_3 - a_1)/3$ is the isovector πN scattering length, $\vec{t}$, $\vec{\tau}$ are pion and nucleon isospin vectors, respectively.

For b_0 and b_1 one has from [4]:

$$b_0 = -0.011 \pm 0.010\ fm, \qquad b_1 = -0.136 \pm 0.010\ fm.$$

The relative accuracy for b_1 equals to 7%, while it is 90% for b_0, so the isoscalar pion-nucleon scattering length is practically uncertain.

The b_0 value has a close relation to such a fundamental problem of hadron physics as a chiral symmetry breaking. It is well known that b_0 is zero for zero pion mass (chiral limit) or under the condition of the validity of the soft pion theorem [5]. The knowledge about the value b_0 would yield the important information on the mechanism of the chiral symmetry breaking. So measuring the isoscalar pion-nucleon scattering length b_0 and refining the isovector one b_1 remains an important experimental problem.

2. Measurement of the π^--meson mass

The most accurate values of the π^--meson mass were obtained by measuring the energy of the transitions between high states of pionic atoms, where the strong pion-nucleus interaction is small [6,7]. The accurate value of the charged pion mass is necessary, for example, to estimate the mass of the muonic neutrino m_{ν_μ}. At present the mass limit for m_{ν_μ} is obtained from the study of the decay of the stopped π^+ mesons: $\pi^+ \to \mu^+ + \nu_\mu$, the muon momentum being measured with high accuracy ($\sim 4ppm$ [8]) and up-to-date values of the pion and muon masses are used. The improvement of the measurement accuracy for these values allowed one to lower the limit for the neutrino mass

$$\begin{aligned} \text{from} \quad & m_{\nu_\mu} < 2.7MeV \quad \text{in 1967 [6]} \\ \text{to} \quad & m_{\nu_\mu} < 0.27MeV \quad \text{in 1986 [7].} \end{aligned}$$

However in [7] the ambiguity appeared, caused by the uncertainty in the electron screening correction when calculating the transition energy in the pionic atom. In general the

X-ray line consists of three components depending on the number of K-electrons present during the transition, which can be equal to 0, 1 or 2. The influence of other electron shells may be neglected. The problem is that the intensity ratio for these components is not known, so the screening correction for the unresolved transition has the uncertainty of the order of the distance between the components. In [7] to obtain the π^--meson mass the $4f-3d$ transition in pionic Mg was chosen, the energy being measured by a focusing crystal-diffraction spectrometer. For transition energy 25.9 keV the energy resolution turned out to be ~ 0.93 eV, which was too rough to resolve the transition components with $\Delta E \sim 0.5$ eV.

In 1994 the data of [7] were reanalyzed, yielding two possible m_π^- values, corresponding to one or two electrons in the K-shell [9]. The difference between these values is six times larger than the experimental pion mass error. The authors of [10] choose one of the possible mass values which (assuming that $m^2_{\nu_\mu} \geq 0$) does not contradict their results on the measurement of the muon momentum in the decay $\pi^+ \to \mu^+ + \nu_\mu$. They obtain as a result

$$m_{\nu_\mu} \leq 0.16 \text{ MeV} \qquad (90\% \text{ C.L.}).$$

In our opinion such a procedure is not quite correct, because one has no reasons to rule out the other possible value of m_π^-. One needs a new accurate measurement of the pion mass to eliminate this ambiguity.

3. Present status of the MADIS-project

In 1995 the two-flat-crystal diffraction spectrometer has been built. It was constructed with the account of the experimental conditions at the Moscow meson factory. The spectrometer allows to measure X-ray energy in the range 2.5 keV$-$100 keV. Double-crystal devices have efficiency comparable with that of the focusing spectrometers, but their resolution is better due to the absence of the apperture aberrations. The resolution is determined by the properties of the monocrystals used and can be optimized for a specific task by choosing the crystal type. The investigation of the spectrometer was carried out using the characteristic X-rays. The energy resolution of the device turned out to be ~ 0.6 eV in the region of $3p-1s$ transition in the pionic hydrogen atom ($E = 3$ keV), the natural linewidth being equal to ~ 0.9 eV.

To obtain the energy shift of the $1s$-level of pionic hydrogen with the accuracy 1% one should measure the energy of the $3p-1s$ transition with the accuracy 0.05 eV. It is possible if one uses for calibration K_{α_1} and K_{α_2} lines of Ar with energies $E = 2957.790 \pm 0.009$ eV and $E = 2955.661 \pm 0.012$ eV respectively. The energy resolution of the spectrometer allows one to measure the width of the $3d$ -- $1s$-transition (0.9 eV). The accuracy of the measurement depends on the statistics and hence on the time to obtain this statistics.

In the 25 keV region the spectrometer has an energy resolution 0.3 eV, which allows one to repeat the measurement of the $4f-3d$ transition in pionic Mg [7]. The components corresponding to 1 or 2 electrons in the K-shell can be resolved. Investigation of the background and other experimental conditions at the MMF proton beam will allow to choose proper pionic atoms for accurate measurement of the π^--meson mass (better than $3\,ppm$).

Since the luminosity of the diffraction spectrometers is extremely low (10^{-9}) we plan to use a "Gatchina-type" target, which was used firstly at LNPI in 1976. In this technique the mesic-atom target is placed near the pion-producting one, which makes it possible to increase the density of the pion stops by a factor of $10^2 - 10^3$.

In 1995 a cryogenic target was constructed comprising a cylinder of 160 *mm* diameter and 400 mm length filled with 1-2 atm hydrogen at 70-80 K temperature. The pion producting target containing 20 tungsten foils with the total thickness 2 mm along the proton beam is placed inside the cylinder in the shadow of the multi-slit collimator plates. Negative pions are produced by a proton beam passing through the foils. Some part of them stop in hydrogen forming pionic atoms. About 300 W of the heat produced by the 50 μA proton beam is removed by a forced circulation of the hydrogen gas in the target volume and by liquid nytrogen cooling. According to calculations to keep hydrogen inside the target at 80 K it is enough to provide the gas velocity 0.5 m/s, the foil temperature remaining below 290 K. The distance from the cold source and the target amounts to 8 m. The liquid nytrogen expenditure is 170 l per day. The cryogenic target connected with the multi-slit 3 m length collimator should be placed into a barrel filled with helium (to decrease the absorption of the soft X-radiation). Solid-state mesic X-ray targets, if necessary, can be located close to the tungsten foils, circulating hydrogen being used to remove the heat produced by the beam.

In 1996 the experimental equipment will be mounted in the MMF experimental hall for testing. When the proton beam of proper parameters is available (energy not less than 500 MeV, current 30-50 μA) we plan to begin measurements.

REFERENCES

1. *Petrov N.M.* Preprint ITP-85-91-E, Kiev, 1985.
2. *Deser S. et al.,* //Phys.Rev., 96. 1954. 774.
3. *Amalsky G.M. et al.,* Preprint LNPI-337. 1977, 21p.
4. *Aschenauer E.C. et al.,* PSI Annual Report 1994/Annex 1. P.34.
5. *Weinberg S.* //Phys.Rev.Lett., 16. 1966. 879.
6. *Shafer R.E.* //Phys.Rev., 163. 1967. 1451.
7. *Jeckelmann B. et al.,* //Phys.Rev.Lett., 56. 986. 1444.
8. *Assamagan K. et al.,* // Phys.Lett., B335. 1994. 231.
9. *Jeckelmann B. et al.,* //Phys.Lett., B335. 1994. 326.
10. *Assamagan K. et al.,* PSI Annual Report 1994/Annex 1. P.15.

NUCLEAR FISSION BEYOND TWO-BODY KINEMATICS

G. E. Solyakin, A. V. Kravtsov

Collinear tripartition of highly excited ^{238}U nuclei [1] requires a generalization of the nuclear fission mechanism. The detection of two massive fragments separating collinearly does not confirm unambiguously the two-body character of the nuclear fission reaction. This experimental result is a necessary but not a sufficient sign of two-body kinematics. Sticking to the experimentally observed two collinear fragments one can see, that this situation could have been realized in a more general case, when the classical liquid drop is fissioning into three fragments, the third fragment being at rest.

The nuclear fission reaction should be written in this case as

$$^{M_0}Z_0 \rightarrow ^{M_1} Z_1 + ^{M_3} Z_3 + ^{M_2} Z_2, \qquad (1)$$