High Resolution Particle Spectroscopy in $^{208}$Pb

1. I want to talk about high resolution particle spectroscopy with the Q3D magnetic spectrograph of the Maier-Leibnitz-Laboratorium at München. We have studied the inelastic proton scattering on $^{208}$Pb.

Protons are accelerated to energies between 14 and 18 MeV and detected by the Q3D magnetic spectrograph at scattering angles between 20° and 140°. A spectrum of 1 MeV length is gathered in typically half an hour with sufficient statistics.

2. Here you see a short spectrum of 60 keV length on a logarithmic scale. The energy of the protons is about 11 MeV.

The line shape is asymmetric. The instrumental resolution as measured for protons without energy loss in the target is 3 keV.

Towards the right side of the peak, protons with lower energy are displayed; here an exponential tail appears, linear on the logarithmic scale. (The peak-to-valley ratio is 100.) The width of the tail depends on the effective target thickness.

3. The lowest states in the doubly magic nucleus $^{208}$Pb are described as particle-hole configurations, either neutrons or protons. In each group of particles or holes there is an intruder. Therefore about 30% of the states have positive parity.

We studied the positive parity particle-hole states built with the intruder particle $j_{15/2}$ and the neutron holes $p_{1/2}$, $f_{5/2}$, $p_{3/2}$. We also studied all negative parity states built with any neutron particle.

4. We are using the method of inelastic proton scattering via isobaric analog resonances. Let me shortly explain.

In the doubly magic nucleus $^{208}$Pb there are 44 excess neutrons. By adding one neutron a particle state in $^{209}$Pb is created. The isobaric analog of such a state consists of 45 components. In each component one excess neutron is converted into a proton.

5. In the proton decay of an analog resonance (IAR) either the proton escapes with the unchanged energy; this corresponds to the elastic proton scattering. Or $^{208}$Pb is left in an excited state and a coherent superposition of up to 30 neutron particle-hole configurations is created in the state.

The proton energy can be precisely measured; relative distances between two states can be determined with an uncertainty of 100 eV up to excitation energies of 8 MeV.

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Inelastic proton scattering via isobaric analog resonances has many advantages; I will mention only a few.

By adjusting the proton energy to a certain analog resonance, the neutron particle of a particle-hole configuration can be chosen.

By measuring excitation functions the parity of each state can be determined; namely only configurations with an intruder excite positive parity states.

If essentially only one configuration contributes to the cross section of the state, the shape of the angular distribution is given by pure geometry and the spin can be determined.

6. Here I show pp’-spectra taken on different IAR. Three states are exclusively excited in the $g_{9/2}$ IAR; the peaks vanish on higher IAR. Five states are exclusively excited in the $j_{15/2}$ IAR; they vanish in the lower or higher IAR.

I now show an extract of spectra fitted by the deconvolution program GAS-PAN.

7. Within 100 keV ten states are identified.

To the left a $7^+$ state with dominant structure $j_{15/2}p_{3/2}$ is excited. To the right, the outer states in a triplet have spin $6^-$, $7^-$ and dominant structure $g_{9/2}f_{7/2}$. The middle member with spin $4^+$ does not show any resonant behaviour.

Within 10 keV five states are seen at $E_x = 5.65$ MeV. The highest state of the quintuplet is excited by the intruder IAR only; it has spin $9^+$. The next state is excited both on the $g_{9/2}$ and $d_{5/2}$ IAR; it has spin $4^-$. The distance between the $4^-$ and the $9^+$ states is $400 \pm 100$ eV.

I now show the angular distributions for the $6^-$, $7^-$ states.

8. They are well described by the single configuration $g_{9/2}f_{7/2}$; they contain 10% of a proton configuration. In addition you see the corresponding $8^-$ state which is almost pure. The deep minimum at $90^\circ$ is characteristic for the configuration with the highest spin of a particle-hole multiplet.

9. Excitation functions were taken from 14 to 18 MeV proton energy.

The parity of the four states is unambiguously determined. The 5127 state is excited exclusively in the $d_{5/2}$ IAR, the three $7^+$ states in the $j_{15/2}$ IAR. They have the structure $j_{15/2}$ coupled to $p_{1/2}$, $f_{5/2}$, $p_{3/2}$.

The width of the $j_{15/2}$ resonance is 210 keV while the distance between the $j_{15/2}$ and $d_{5/2}$ IAR is 120 keV.
10. For positive parity states with spins $5^+$, $6^+$, $7^+$, $8^+$, $9^+$, $10^+$ almost all states below 6 MeV predicted by the shell model are identified.

The energies predicted by the shell model without residual interaction (SM) are shown at left, the experimental energies at right.

For each state several particle-hole configurations are determined. The states containing the strongest component of the configurations built with a $j_{15/2}$ particle and $p_{1/2}$, $f_{5/2}$, $p_{3/2}$ holes are identified.

Similarly, for negative parity states almost all states below 6 MeV predicted by the shell model are identified.

11. (Summary)

By using the Q3D magnetic spectrograph of the Maier-Leibnitz-Laboratorium at München, we have performed experiments of $^{208}\text{Pb}(p, p')$ via IAR in $^{209}\text{Bi}$ with an instrumental resolution of 3 keV. The line shape, however, is asymmetric with an exponential tail proportional to the effective target thickness.

Relative distances of two states in a doublet can be determined with a precision of 100 eV.

For excitation energies below 6 MeV from 120 states predicted by the shell model, 80 states with negative parity and 30 states with positive parity are identified with their spin, parity and dominant particle-hole structure.