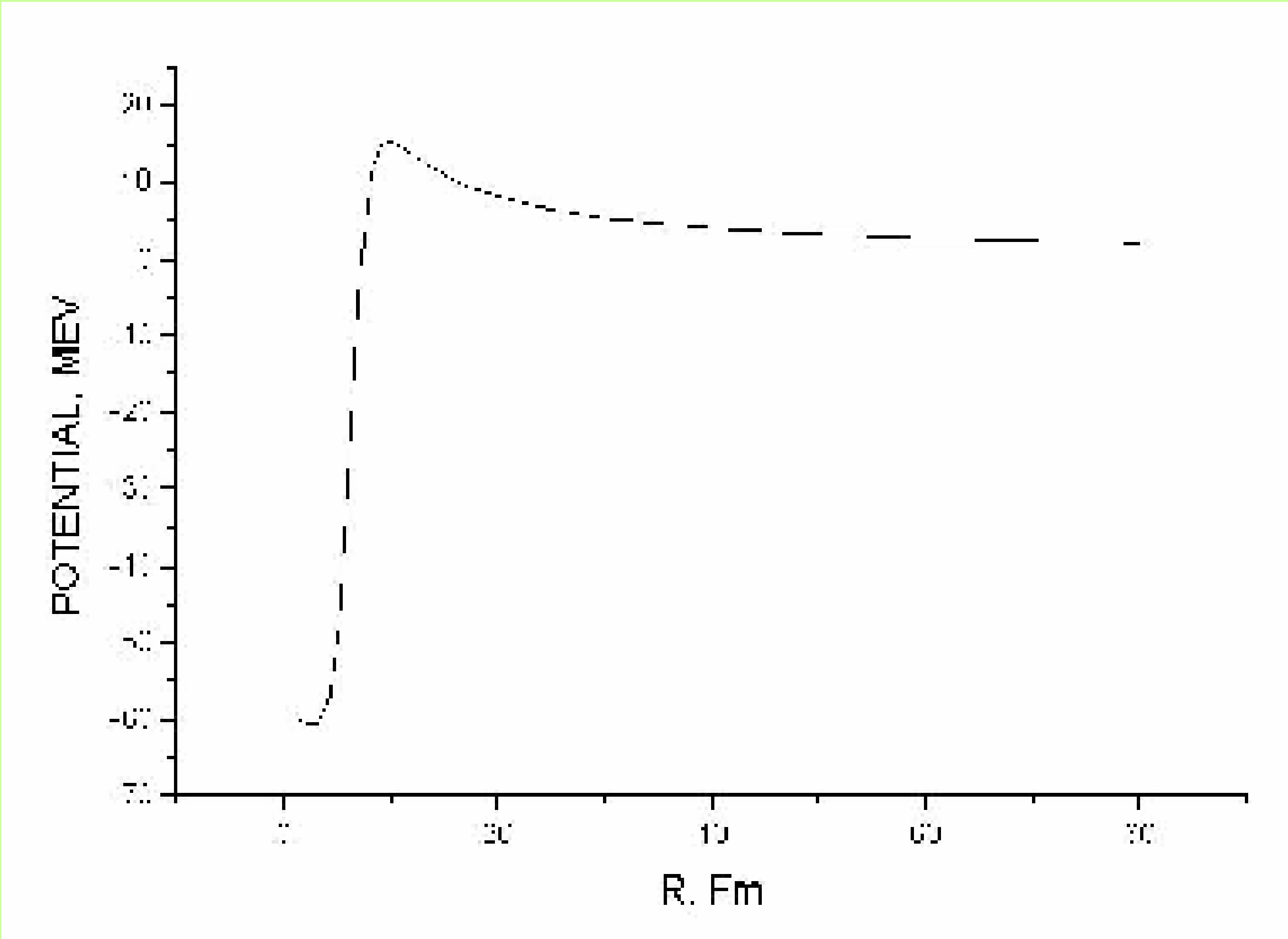
GIANT RESONANCES and ANGULAR DISTRIBUTION IN ALPHA DECAY

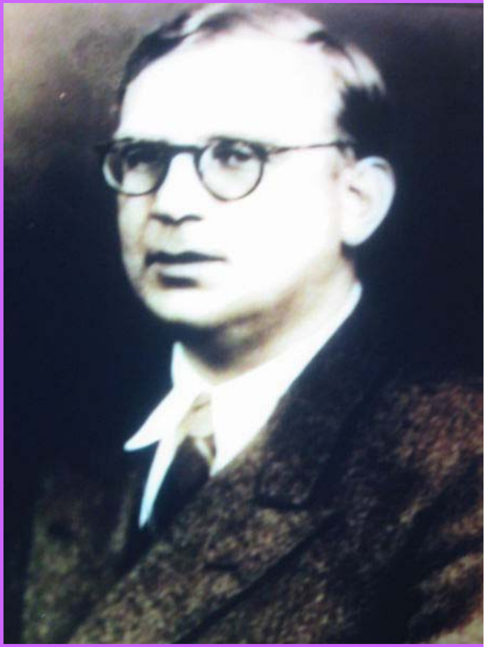
F.F.Karpeshin

Tunneling of α particles through the Coulomb barrier is consecutively treated. The effect of sharp peaks arising in the case of coincidence of the α energy with that of a quasistationary state within the barrier is elucidated. Peaks' energy depend on the α-nucleus potential. The peaks can also be observed in the incoming α-nucleus channel. The method is also applied for calculation of the angular distribution of the emitted α particles from the α decay of a compound nucleus of ^{135}Pr.

α -nucleus potential for the system of $^{131}La + \alpha$



- The theory was proposed by Gamov as an extension of the theory of *quasistationary states* by introducing the complex energy as an eigenvalue. In this theory, the real part of the energy has the physical sense of the α eigenvalue, and the imaginary part gives the probability of tunneling through the barrier.

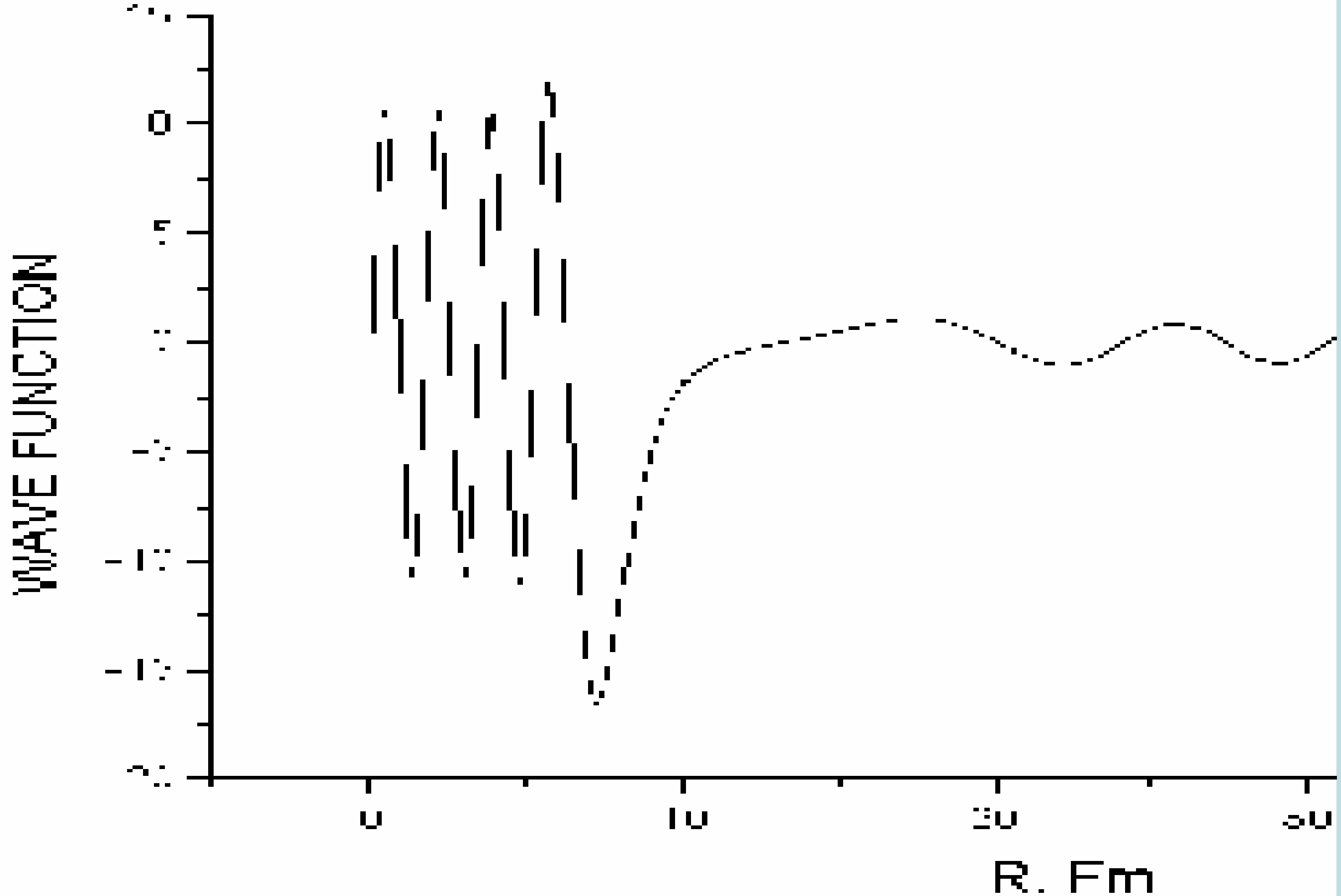


BUT:

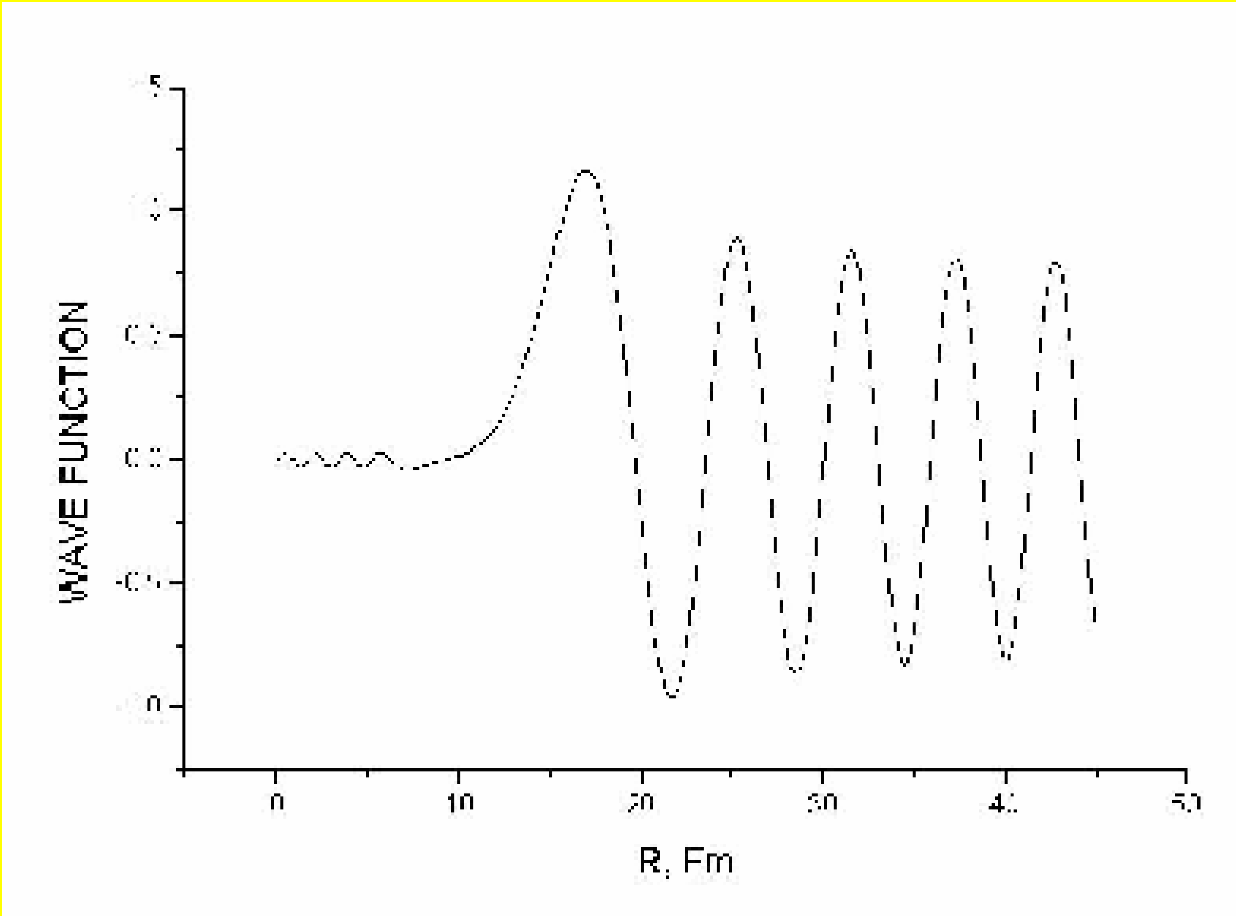
there are ***no*** *quasistationary α orbits in the nuclei. They are only formed virtually, mainly on the nuclear surface. Then they have a chance to escape through the barrier, otherwise they are immediately destroyed and absorbed by the bulk of the nuclear matter.*

This means that α's may be with an arbitrary energy.

α wavefunction for the system of $^{131}La + \alpha$ with the *resonance* α energy of 10.79 MeV



α wavefunction for the system of $^{131}La + \alpha$, with α *nonresonance* energy of 14 MeV



HOW to DEFINE the tunneling probability?

Natural idea which can be expressed from the first principles:

to *project* the shell-model wavefunction on to the CHANNEL w.f.

Transparency acquires a new sense: the channel w.f. may be small or great in the nuclear region.

CONCLUSION

- There is no need to fit the α-nucleus potential by adjusting the α energy to an eigen state inside the barrier.

- GR are predicted in the α-nucleus interaction. Discovering them will help to fix the parameters of the potential.

SUMMARY

- Finding the predicted GR looks a challenging but fairly feasible problem at the present stage of investigations.

nucleons constituting the α particle:

$$\langle \varphi_f(\mathbf{r}_1, \ldots, \mathbf{r}_{A-4}) | \Psi(\mathbf{r}_1, \ldots, \mathbf{r}_A) \rangle = \eta(\mathbf{r}_{A-3}, \ldots, \mathbf{r}_A) \, . \tag{6}$$

The resulting product can be called α cluster in the adiabatic representation. Within the framework of the shell model, its wavefunction vanishes outside the nuclear surface.

Therefore, we have to relate the shell-model wavefunction of the source nucleus to the channel wavefunction (1). Then the re-expansion coefficients give the transition amplitude under consideration. This way is similar to that found by Migdal when solving his classical problem of shake of an atom in β decay.[13] To find the transition amplitude, one has to project the right part of eq. (1) onto the primary wavefunction Ψ:

$$M_{f\mathbf{p}} = \langle g_{\mathbf{p}}(\mathbf{r}_{A-3} - \mathbf{R}, \ldots, \mathbf{r}_A - \mathbf{R}) | \eta(\mathbf{r}_{A-3}, \ldots, \mathbf{r}_A) \rangle \, . \tag{7}$$

According to,[9] the α decay amplitude is thus determined by the formation-penetration factor (7), which includes both the formation and penetration amplitudes. One can further break this factor into these conventional amplitudes by inserting the set of the α wavefunctions, reduced to the single ground state ξ of an α particle which is in the point R, and then integrate over R. As a result, we get the following expression:

$$\begin{aligned} M_{f\mathbf{p}} = \langle g_{\mathbf{p}}(\mathbf{r}_{A-3} - \mathbf{R}, \ldots, \mathbf{r}_A - \mathbf{R}) | \xi(\mathbf{r}_{A-3} - \mathbf{R}, \ldots, \mathbf{r}_A - \mathbf{R}) \rangle \times \\ \times \langle \xi(\mathbf{r}_{A-3} - \mathbf{R}, \ldots, \mathbf{r}_A - \mathbf{R}) \eta(\mathbf{r}_{A-3}, \ldots, \mathbf{r}_A) \rangle \equiv \\ \equiv \int_0^\infty \mathcal{F}_p(R) f(R) \, dR \, . \end{aligned} \tag{8}$$

nucleons constituting the α particle:

$$\langle \varphi_f(\mathbf{r}_1,\ldots,\mathbf{r}_{A-4})|\Psi(\mathbf{r}_1,\ldots,\mathbf{r}_A)\rangle = \eta(\mathbf{r}_{A-3},\ldots,\mathbf{r}_A)\,. \tag{6}$$

The resulting product can be called α cluster in the adiabatic representation. Within the framework of the shell model, its wavefunction vanishes outside the nuclear surface.

Therefore, we have to relate the shell-model wavefunction of the source nucleus to the channel wavefunction (1). Then the re-expansion coefficients give the transition amplitude under consideration. This way is similar to that found by Migdal when solving his classical problem of shake of an atom in β decay.[13] To find the transition amplitude, one has to project the right part of eq. (1) onto the primary wavefunction Ψ:

$$M_{f\mathbf{p}} = \langle g_{\mathbf{p}}(\mathbf{r}_{A-3}-\mathbf{R},\ldots,\mathbf{r}_A-\mathbf{R})|\eta(\mathbf{r}_{A-3},\ldots,\mathbf{r}_A)\rangle\,. \tag{7}$$

According to,[9] the α decay amplitude is thus determined by the formation-penetration factor (7), which includes both the formation and penetration amplitudes. One can further break this factor into these conventional amplitudes by inserting the set of the α wavefunctions, reduced to the single ground state ξ of an α particle which is in the point R, and then integrate over R. As a result, we get the following expression:

$$\begin{aligned} M_{f\mathbf{p}} = \langle g_{\mathbf{p}}(\mathbf{r}_{A-3}-\mathbf{R},\ldots,\mathbf{r}_A-\mathbf{R})|\xi(\mathbf{r}_{A-3}-\mathbf{R},\ldots,\mathbf{r}_A-\mathbf{R})\rangle\times \\ \times\langle\xi(\mathbf{r}_{A-3}-\mathbf{R},\ldots,\mathbf{r}_A-\mathbf{R})\eta(\mathbf{r}_{A-3},\ldots,\mathbf{r}_A)\rangle \;\equiv \\ \equiv \int_0^\infty \mathcal{F}_p(R)f(R)\;dR\,. \end{aligned} \tag{8}$$

In (8), $f(R)$ can be considered as a wavefunction of an α particle inside the nucleus. The preformation probability P is therefore included in this factor:

$$P = |\int_0^\infty f(R)\;dR|^2\,. \tag{9}$$

The conventional spectroscopic factor s for α decay is given by the overlapping integral

$$s = \int_0^\infty \langle\xi(\mathbf{r}_{A-3}-\mathbf{R},\ldots,\mathbf{r}_A-\mathbf{R})|\eta(\mathbf{r}_{A-3},\ldots,\mathbf{r}_A)\rangle\;dR = \int_0^\infty f(R)\;dR\,. \tag{10}$$

On the other hand, the other overlapping integral in (8) gives the tunneling probability t:

$$t = |\int_0^\infty \mathcal{F}_p(R)f(R)\;dR\;|^2. \tag{11}$$

Furthermore, taking into account the asymptotics (3), the wavefunction $\mathcal{F}_{\mathbf{p}}(\mathbf{R})$ can be expressed in terms of the spherical harmonics in a usual way:

$$\mathcal{F}_p(\mathbf{R}) = \sum_{\ell=0}^{\infty} i^\ell(2\ell+1)e^{-i\delta_\ell}R_{p\ell}(R)Y_{\ell m}(\theta,\varphi)\,. \tag{12}$$