since the excitation function has a small width, although the experimental errors do not make the conclusions in this respect unambiguous. There is likewise no proton evaporation, which would lead to Bk isotopes, since no spontaneous fission having the same period was observed in the reaction $U^{238} + N^{15}$, which leads to Bk isotopes by evaporation of an α particle and several neutrons.

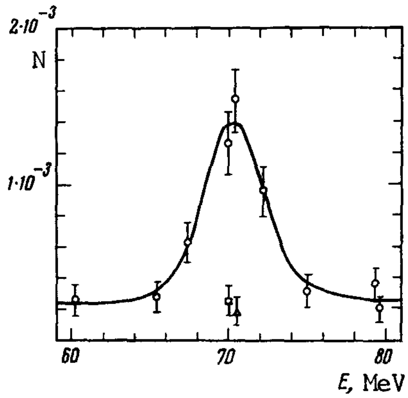

Fig. 2. Excitation functions of the $U^{238} + C^{12}$ reaction leading to spontaneously fissioning isomer. o - Effect, Δ - background, N - number of tracks per Maxwell, E - ion energy.

Comparison of the excitation function with the known data [4] on the production of the ground state of Cf isotopes in the reaction $U^{238}(C^{12}, xn)Cf$ allows us to assume that the observed spontaneously-fissioning isomer belongs to the isotope Cf^{246}. The cross section of the reaction $U^{238}(C^{12}, 4n)Cf^{246m}$ at the maximum of the excitation function (at 70 ± 2 MeV) is $(1.2 \pm 0.5) \times 10^{-32}$ cm^2. By comparison, the maximum cross section of the reaction with production of Cf^{246} in the ground state (at 68 MeV) is 3×10^{-29} cm^2 [4].

The half-life of Cf^{246} relative to spontaneous fission is 2.1×10^3 years. This means an increase by a factor 10^{18} in the probability of spontaneous fission for the isomer state.

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STATISTICAL SCATTERING AND THE OREAR FORMULA

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An important role is played in large-angle scattering of strongly-interacting high-energy particles by statistical processes and the diffraction associated with them [1].

Therefore at large angles we have

$$d\sigma/d\Omega = (d\sigma/d\Omega)_{st} + (d\sigma/d\Omega)_{dif}, \quad (1)$$

$$(d\sigma/d\Omega)_{st} = \frac{1}{4p^2} \sum_{\ell} (2\ell + 1)^2 P_\ell^2(\cos\theta)(2 \operatorname{Re} f_\ell - |f_\ell|^2) W_2, \quad (2)$$

$$(d\sigma/d\Omega)_{dif} = \frac{1}{4p^2} \left| \sum_{\ell} (2\ell + 1) f_\ell P_\ell(\cos\theta) \right|^2. \quad (3)$$

Here f_ℓ is the partial amplitude of the diffraction statistical scattering, p the c.m.s. momentum, W_2 the ratio of the phase volume of the elastic channel to the total phase volume, and θ the c.m.s. scattering angle.

The first term in (1) prevails at larger angles and the second at smaller ones.

Further, $(d\sigma/d\Omega)_{st}$ is symmetrical about $\theta = \pi/2$ in the c.m.s., whereas $(d\sigma/d\Omega)_{dif}$ is asymmetrical and decreases with increasing θ. From the condition $(d\sigma/d\Omega)_{dif} = (d\sigma/d\Omega)_{st}$ we can determine the energy-dependent value of the angle θ_{cr} at which both scatterings are equal. If $\theta_{cr} > \pi/2$, then the total scattering $d\sigma/d\Omega$ is not symmetrical about $\pi/2$. Therefore, if experiment yields such a symmetry, this means that the diffraction is already negligible. Getting ahead of ourselves, we note that, in our opinion, the opposite case occurs in elastic $\tilde{p}p$ scattering at $P_0 = 3, 4, 5$, and 7 (P_0 is the momentum of the incident beam in the working system) [4]. The values of $(d\sigma/d\Omega)_{dif}$ and θ_{cr} depend, generally speaking, on the choice of the parameters that define the distribution of the transparency, and consequently on the character of the scattered particles. In calculating the diffraction it is convenient to use the optical model and to choose the dependence of the transparency on the distance R in the form [1)]

$$d = 1 - f = 1 - \frac{b}{(1 + \alpha^2 R^2)^2}. \quad (4)$$

Further [3], $W \sim \exp(-AE')$, where E' is all the energy that can go into production of new particles, $E' = E_c - 2m_N$ for pp collisions and $E = E_c$ for $\tilde{p}p$ collisions (E_c is the total c.m.s. energy of the system).

We wish to call attention in this note to two curious circumstances.

1. Using (1), (4), and the asymptotic expression

$$P_\ell(\cos\theta) \sim \left[\frac{2}{\pi\ell \sin\theta}\right]^{\frac{1}{2}} \sin\left[(\ell + \tfrac{1}{2})\theta + \frac{\pi}{4}\right]$$

we obtain

$$d\sigma/d\Omega = \frac{5}{6}\frac{\pi}{\alpha^2} b \frac{\exp(-AE')}{\sin\theta} + \frac{b^2}{\sin\theta}\frac{1}{\alpha^2}\frac{p}{\alpha}\frac{\pi}{8}\left[\frac{p\theta}{\alpha} + \frac{1}{2}\right]^2 \exp\left[-\frac{2p}{\alpha}\theta\right], \quad (5)$$

where the first term is $(d\sigma/d\Omega)_{st}$ and the second is $(d\sigma/d\Omega)_{dif}$. Let us consider $d\sigma/d\Omega$ as a function of $p_\perp = p \sin\theta$ and θ, and let us calculate the slope of its semilog plot, $\gamma = \frac{d}{dp_\perp} \ln (d\sigma/d\Omega)$.

Assuming $p_\perp > 1$ BeV/c, we obtain for the two regions $\theta < \theta_{cr}$ (when $(d\sigma/d\Omega)_{dif}$ prevails) and $\theta > \theta_{cr}$ (when $(d\sigma/d\Omega)_{st}$ prevails)

$$\gamma = \frac{1}{\gamma_1} \approx \frac{1}{p_\perp} - \frac{2}{\alpha}\frac{\theta}{\sin\theta} \approx -\frac{2\theta}{\alpha\sin\theta} \qquad (\theta < \theta_{cr}),$$
$$\gamma = \gamma_2 \approx -\frac{2A}{\sin\theta} \qquad (\theta > \theta_{cr}) \,. \tag{6}$$

Using experiments [5] on pp scattering at sufficiently high energy in the region $\theta \approx \pi/2 > \theta_{cr}$, we determine γ_2 and consequently $A \approx (\gamma/2)\sin\theta \approx \gamma_2/2$. The absolute value of the cross section at $\theta = \pi/2$ yields $b/d^2 \approx 4\ (\text{BeV})^{-2}$. Further, according to Orear [2], the experimental results are described over a wide range of $p_\perp$ by a single curve

$$(d\sigma/d\Omega)_{\text{Orear}} = \frac{600}{E_c^2}\exp\left[-\frac{p_\perp}{0.158}\right] \qquad (p_\perp \text{ in BeV/c})$$

and consequently relations (1) and (4) describe the experiment if $\gamma_1 \approx \gamma_2 \approx \gamma_{\text{Orear}} \approx -6.3$, i.e., $\alpha \approx (1/3.2)(\theta/\sin\theta)$. We assume, finally, the values

$$A = 3.4\ (\text{BeV})^{-1} \approx \frac{1}{2.1\mu}\ ; \quad b = 0.4; \quad \alpha = 0.32\ \text{BeV/c} \approx 2.3\mu \tag{7}$$

(μ is the pion mass). We note that a theoretical estimate [3] yields $A = (2.2\mu)^{-1}$. Consequently we have essentially only two parameters to choose, α and b. The dimension of the opacity region at such a value of α, according to (4), turns out to be reasonable. Thus, from the relation $(d\sigma/d\Omega)_{st} = (d\sigma/d\Omega)_{dif}$ we determine the value of θ_{cr}. As $E \to \infty$ we get $\theta_{cr} \approx (\alpha/2)(E'A/p) \approx \alpha A \approx 61°$.

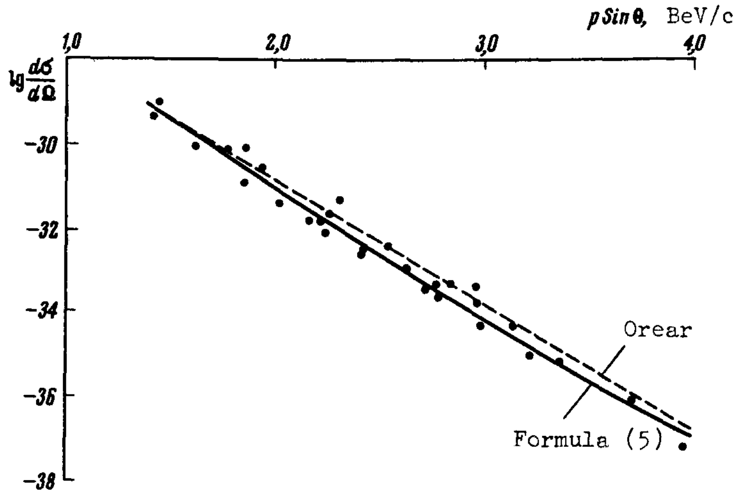

Fig. 1

Figure 1 shows a plot of (5) (with allowance for (7)) and of Orear's formula [2], as well as the experimental data (points). We see that all the deviations are within the limits of experimental error.

Thus, Orear's formula can be regarded as a good approximation of (5). At relatively small variations of α (and even large variations of b), Orear's formula remains a good approximation. This is true also when the transparency distribution changes, for example if a Gaussian form is used in lieu of (4).

2. Even for fixed values of b and α, but on going over to $\tilde{N}N$ scattering, it may turn out that Orear's formula no longer holds, for another reason. Indeed, in this case all the c.m.s. energy ($E' = E_c$) may go into production of the new particles. The probability of the two-particle channel is then decreased. This is reflected in the fact that the second term in (8) must be multiplied by $\exp(-2Am_N) \approx e^{-6.4} \approx 2 \times 10^{-3}$. Using the same values of the remaining coefficients as before, we obtain for θ_{cr} the values shown in Fig. 2.

We see that at energies up to $E_c \sim 10$ BeV, the main contribution to pp scattering in the region $\theta \lesssim \pi/2$ is made by diffraction. In this connection, we call attention to the experimental data discussed in [4]. At an energy $E \sim 3.1$ BeV we obtain from Fig. 2 $\theta_{cr} = 1.7$ (100°). Consequently, the scattering need not be symmetrical about $\pi/2$. It should not be described by the Orear formula, as is apparently the case in practice. This conclusion is reached for any other form of transparency, such as Gaussian.

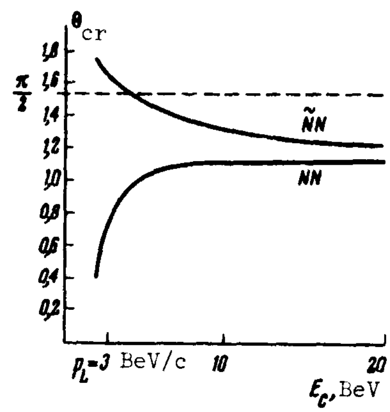

Fig. 2

Conclusions

1. The universal Orear formula can be interpreted as the result of joint action of the statistical scattering and diffraction due to all statistical processes (Fig. 1).

2. Since large-angle elastic scattering is governed, in general, not only by statistical scattering but also by diffraction statistical scattering, it follows that elastic $p\tilde{p}$ scattering at not too high energies is asymmetric about 90°, in accord with experiment [4]. With increasing energy, when θ_{cr} becomes smaller than 90° (see Fig. 2), we can expect the appearance of symmetry.

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