

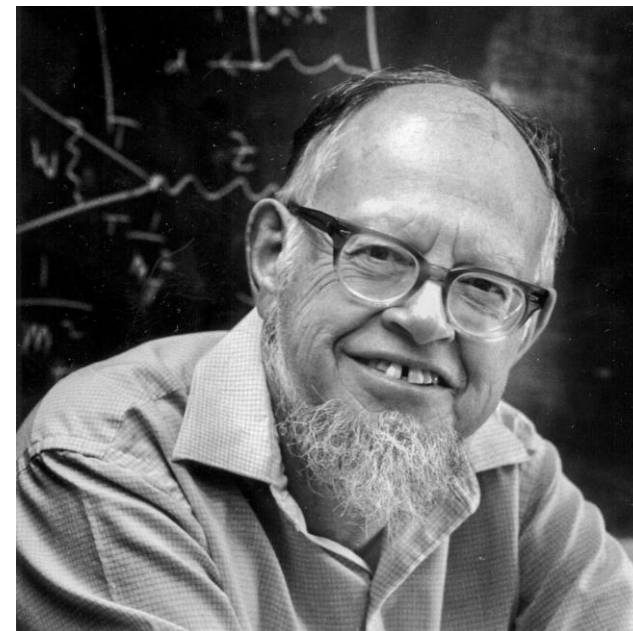
MSW



**Станислав Павлович Михеев**



**Алексей Юрьевич Смирнов**



**Линкольн Вольфенштейн**

$$i \frac{d\psi_f}{dt} = \left( k\hat{I} + \frac{\hat{M}^2}{2k} + \hat{W} \right) \psi_f;$$

$$i \frac{d\psi_f}{dt} = \hat{H}\psi_f,$$

$$W = W_e - W_\mu = \sum_i \Delta f_i(0) N_i k^{-1},$$

$$\Delta f(0) = \sqrt{2} G_F k,$$

$$\hat{H} = \begin{vmatrix} H_e & \frac{1}{2} \bar{H} \\ \frac{1}{2} \bar{H} & H_\mu \end{vmatrix},$$

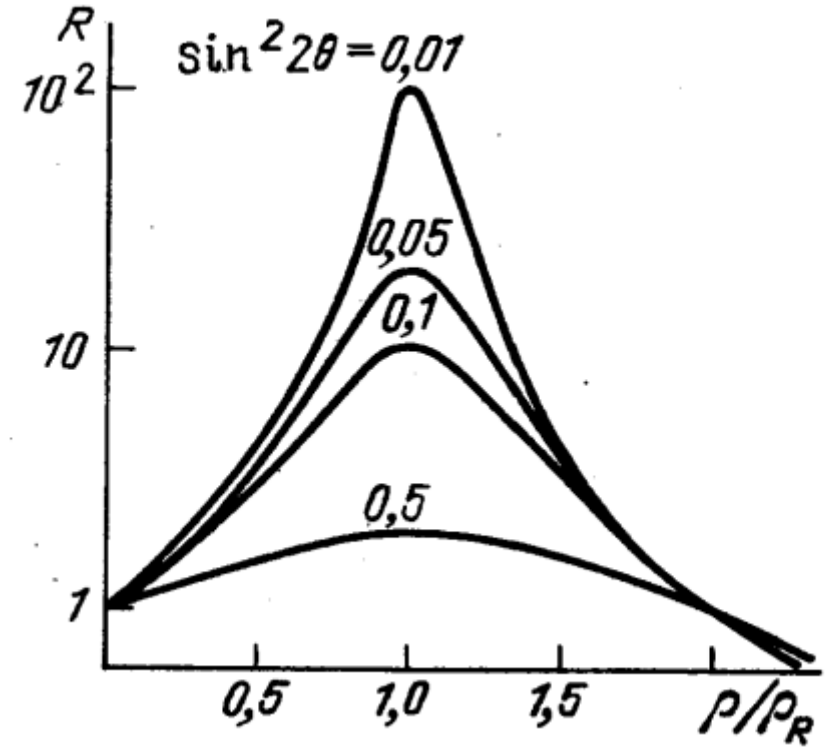
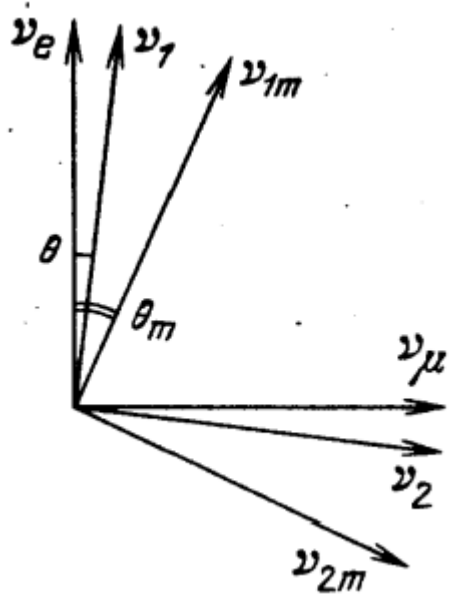
$$W = \sqrt{2} G_F N_e = \sqrt{2} G_F \rho m_N^{-1} Y_e,$$

$$\bar{H} = -\Delta m^2 (2k)^{-1} \sin 2\theta,$$

$$H = H_e - H_\mu = \Delta m^2 (2k)^{-1} \cos 2\theta + \sum_i \Delta f_i(0) N_i k^{-1}.$$

$$H \equiv -2\pi l_\nu^{-1} (\cos 2\theta - l_\nu l_0^{-1}), \quad \bar{H} = 2\pi l_\nu^{-1} \sin 2\theta.$$

$$l_0 = 2\pi m_N (\sqrt{2} G_F \rho Y_e)^{-1} \quad l_\nu = -4\pi k (\Delta m^2)^{-1}.$$

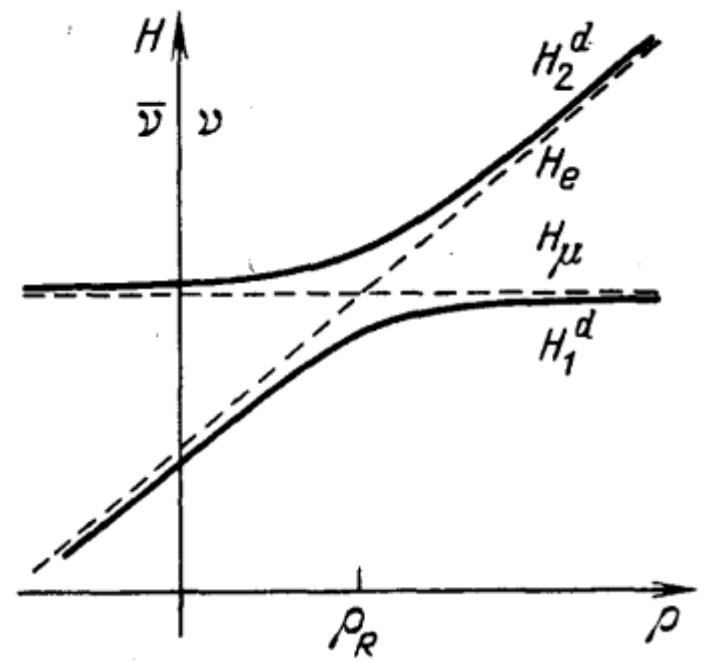
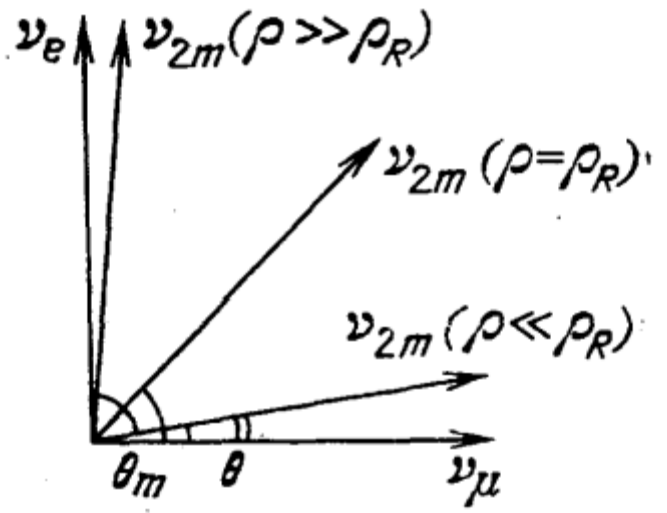


$$\hat{S}_m^+(\theta_m) \hat{H} \hat{S}_m(\theta_m) = \hat{H}_m^{\text{diag}} = \text{diag}(H_1^d, H_2^d).$$

$$\mathbf{v}_f = \hat{S}_m(\theta_m) \mathbf{v}_m, \quad \hat{S}_m(\theta_m) = \begin{pmatrix} \cos \theta_m & \sin \theta_m \\ -\sin \theta_m & \cos \theta_m \end{pmatrix},$$

$$\sin^2 2\theta_m = \sin^2 2\theta \cdot R(l_v l_0^{-1}, \theta),$$

$$R = [(\cos 2\theta - l_v l_0^{-1})^2 + \sin^2 2\theta]^{-1}$$



$$|v(t)\rangle = \cos \theta_a |v_{1m}\rangle + \sin \theta_a e^{-i\varphi} |v_{2m}\rangle;$$

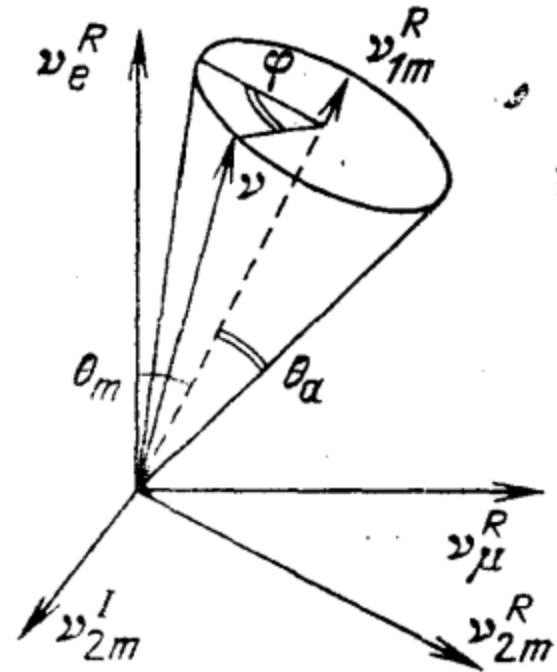
$$\langle v_e | v(t) \rangle = \cos \theta_a \cdot \cos \theta_m + \sin \theta_a \cdot \sin \theta_m e^{-i\varphi}.$$

$$P(t) = \bar{P}(t) + \frac{1}{2} A_P(t) \cos \varphi,$$

$$\bar{P}(t) = \cos^2 \theta_a \cdot \cos^2 \theta_m + \sin^2 \theta_a \cdot \sin^2 \theta_m,$$

$$A_P = \sin 2\theta_a \cdot \sin 2\theta_m$$

$$T_m = l_m = 2\pi \dot{\varphi}^{-1}.$$



$$\psi_f = \hat{S}_m(\theta) \psi_m, \quad \psi_m = (\psi_{1m}, \psi_{2m}).$$

$$i \frac{d\psi_m}{dt} = \hat{H}_m \psi_m,$$

$$\hat{H}_m = \left( \hat{H}^{\text{diag}} - i \hat{S}_m^+ \frac{d\hat{S}}{dt} \right) = \begin{vmatrix} H_1^d & -i\dot{\theta}_m \\ +i\dot{\theta}_m & H_2^d \end{vmatrix}.$$

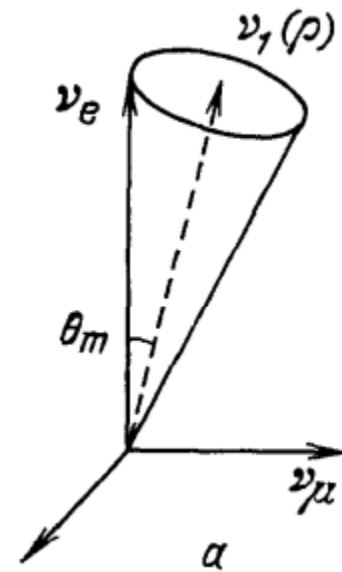
$$\frac{d\theta_m}{dt} = \sin^2 2\theta \cdot \frac{R}{2\Delta\rho_R} \frac{d\rho}{dt} = \frac{\sin^2 2\theta_m}{2\Delta\rho_R} \frac{d\rho}{dt}.$$

$$\dot{\theta}_a = \dot{\theta}_m \cos \varphi,$$

$$\dot{\varphi} = \dot{\varphi}^d - 2\dot{\theta}_m \sin \varphi \cdot \text{ctg } 2\theta_a,$$

$$\dot{\varphi}^d = H_2^d - H_1^d = 2\pi l_m^{-1} = 2\pi (l_v R^{1/2})^{-1}.$$

$$\theta_a^0 = \theta_m^0, \quad \varphi^0 = 0.$$

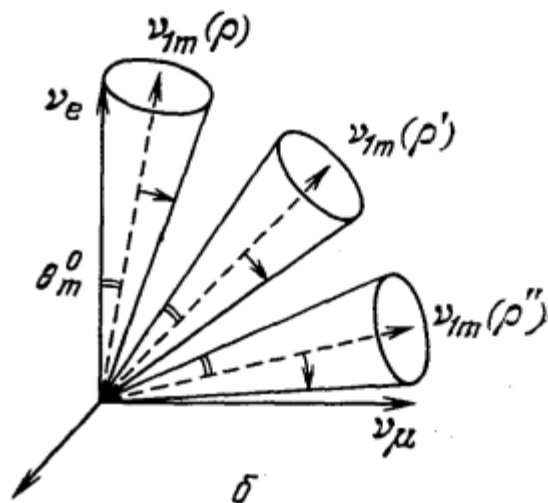


$$\dot{\theta}_m \ll \dot{\varphi}^d,$$

$$\Delta r_R \geq l_m^R$$

$$\theta_a \approx \theta_a^0, \quad \dot{\varphi} = \dot{\varphi}^d$$

$$\Delta r_R = \left( \frac{d\rho}{dr} \right)_R^{-1} \Delta \rho_R$$



Универсальность  
Монотонность

$$\bar{P}(n, n_0) = \frac{1}{2} \{ 1 + nn_0 [(n_0^2 + 1)(n^2 + 1)]^{-1/2} \},$$

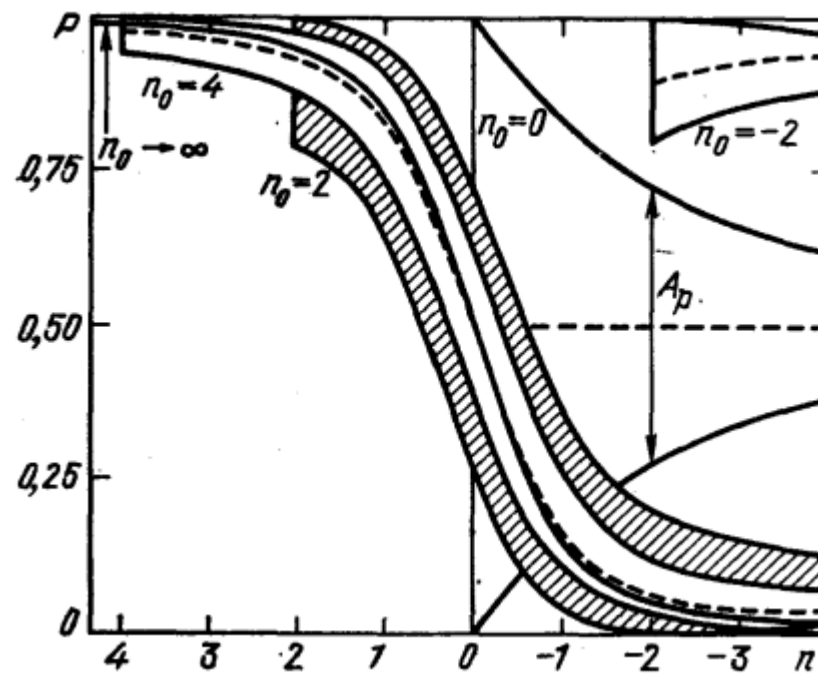
$$A_p(n, n_0) = [(n_0^2 + 1)(n^2 + 1)]^{-1/2}.$$

$$\dot{\theta}_a = \dot{\theta}_m \cos \varphi,$$

$$\dot{\varphi} = \dot{\varphi}^d - 2\dot{\theta}_m \sin \varphi \cdot \text{ctg } 2\theta_a,$$

$$\dot{\varphi}^d = H_2^d - H_1^d = 2\pi l_m^{-1} = 2\pi (l_v R^{1/2})^{-1}.$$

$$\theta_a^0 = \theta_m^0, \quad \varphi^0 = 0.$$





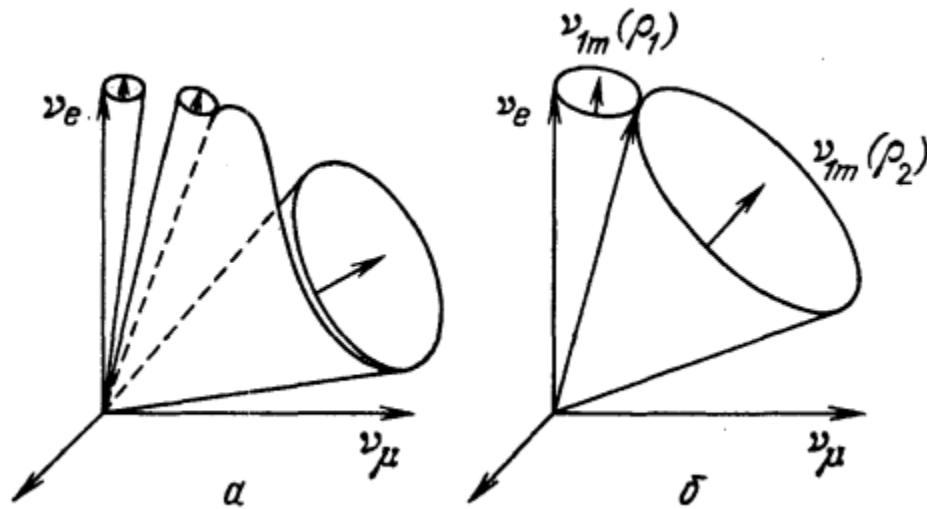


Рис. 9. Графическое представление осцилляции нейтрино.

*a* — Нарушение адиабатичности в резонансном слое.  
*b* — Скачок плотности

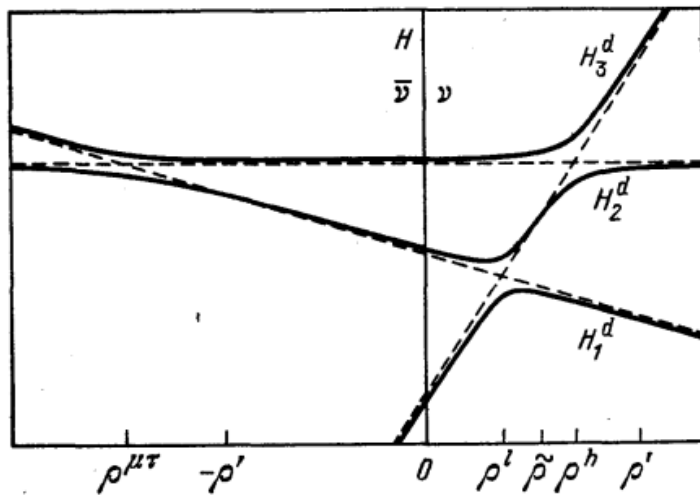


Рис. 11. Зависимость уровней энергии в системе трех нейтрино от плотности среды

$$l_0 = 2\pi W^{-1} = 2\pi \left( \sum_i \Delta f(0) N_i k^{-1} \right)^{-1}.$$

$$l_\nu = -4\pi k (\Delta m^2)^{-1}.$$

$$R = [(\cos 2\theta - l_\nu l_0^{-1})^2 + \sin^2 2\theta]^{-1}$$

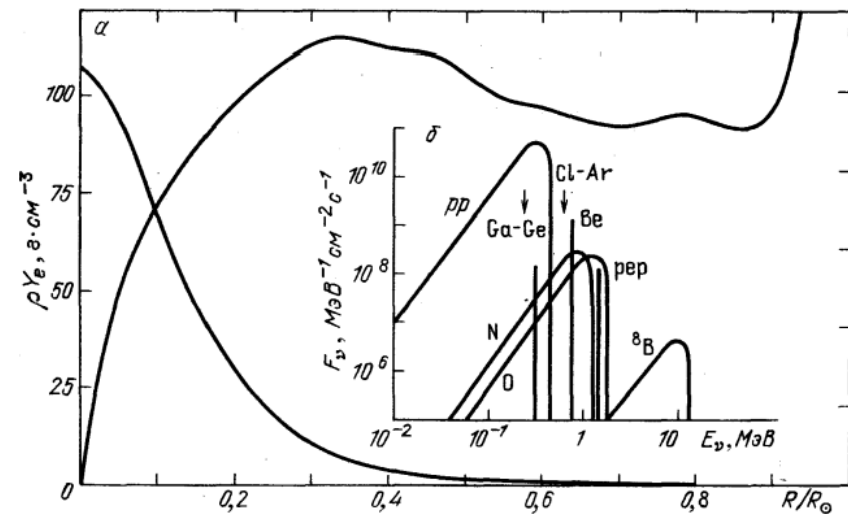
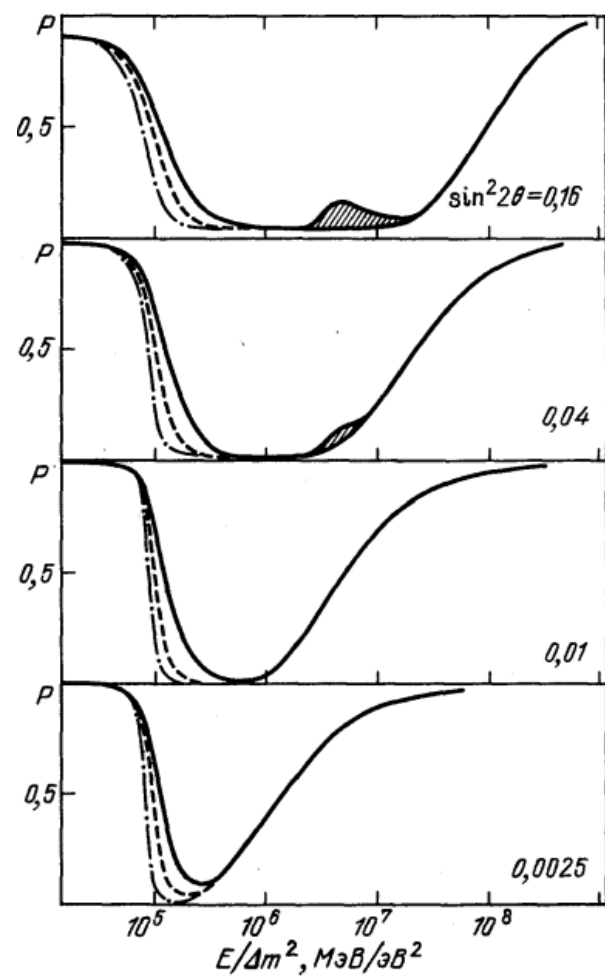
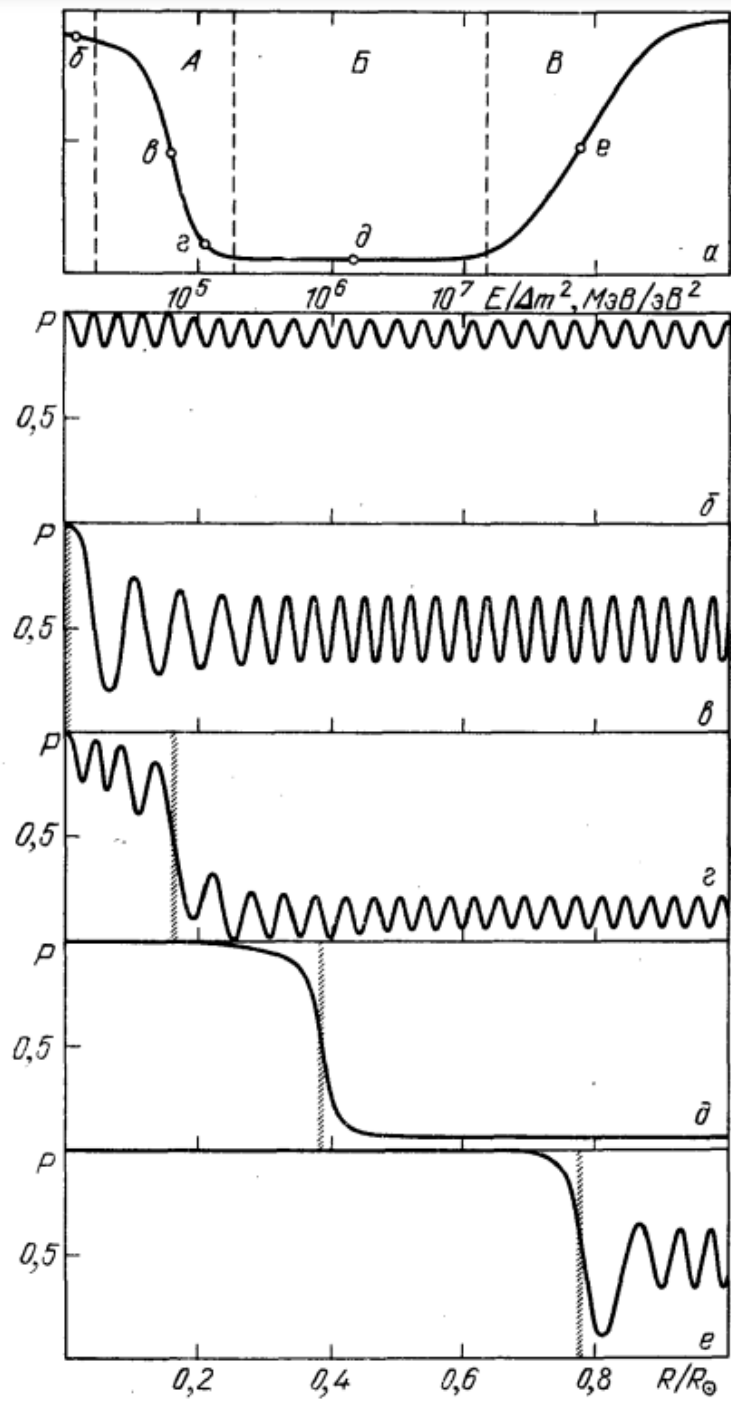


Рис. 16. *a* — Фактор подавления потока  $\nu_e$  в Солнце как функция  $E/\Delta m^2$ . *б* — *e* — Картина осцилляции нейтрино с разными  $E/\Delta m^2$  (расхождение пакетов не учитывается, период осцилляции для наглядности увеличен)

# Solar neutrinos: Oscillations or No-oscillations?

A. Yu. Smirnov\*

$$P_{SNO} \equiv \frac{\Phi_e}{\Phi_{NC}} = 0.340 \pm 0.023 \begin{matrix} +0.029 \\ -0.031 \end{matrix},$$

$$P_{non-osc} = \sin^2 \theta_{12} = 0.31,$$

Direct Evidence for Neutrino Flavor Transformation from Neutral-Current Interactions in the Sudbury Neutrino Observatory

msw|

0/0

