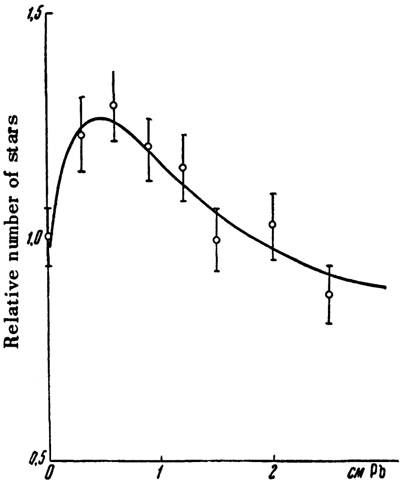
time the average efficiency of a scanner is 80%, therefore the results are strongly affected by the method and the quality of scanning. Thus, for example, as a result of carrying out a single scanning the existence of the maximum in the curve is not very pronounced. We have employed three fold scanning of the same volume of photographic emulsion in which three different scanners took part. This has greatly increased the efficiency of scanning and has lead to the discovery of a sharply pronounced maximum. The small depth at which the maximum in the transition effect of stars occurs may also explain the absence of a transition effect under unfavorable experimental conditions — unfavorable absorber geometry, thick stacks of photographic emulsion, nearby massive objects, etc.



The results obtained by us do not disagree with the results of other investigators.

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ELECTROMAGNETIC INTERACTION WITH PARITY VIOLATION

Ia. B. ZEL'DOVICH

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UNTIL the discovery of violation of parity it was assumed that the interaction of an elementary particle of spin $\frac{1}{2}$ with a weak electromagnetic field was completely described by three terms in the energy

$$q\varphi,\ \mu(\sigma \mathbf{H}),\ a\,\mathrm{div}\,\mathbf{E} = 4\pi a\rho,$$

where σ is the spin, q the charge, μ the magnetic moment and the constant a characterizes the field of a spherical capacitor, equal to zero outside but interacting with a charge ρ inside.[1]

In their well known article about nonconversation of parity, Lee and Yang[2] indicate the possibility of an electrical dipole moment, i.e., an interaction $d(\sigma \cdot \mathbf{E})$. However, if, with parity violation, there is conservation of invariance with respect to combined inversion (and consequently, also with respect to reflection in time) then, as Landau[3] has shown, no dipole moment is possible. It is easiest to see this by noting that under time inversion σ changes sign but **E** does not.

Which electromagnetic interactions, forbidden in the case of parity conservation, are possible in the theory of combined inversion?

The interaction $(\sigma \cdot A)$ is not allowable because of gauge invariance. There remains

$$b(\sigma \Delta A) = b(\sigma \operatorname{curl} H) = \frac{4\pi b}{c}(\sigma j).$$

Here $j = \rho v$ is the current density which produces the magnetic field H. Under conservation of parity such a term would be pseudoscalar (σ is a pseudovector, j a vector) and could not occur in the expression for the energy. On the other hand, both σ and j change sign under time reflection. The moment of force corresponding to such an interaction energy is $M = (4\pi b/c)[\sigma \times j]$.

Such an interaction is directly obtained from a model of virtual decay of a spin-$\frac{1}{2}$ particle A into a particle B of spin 0 and a particle C of spin $\frac{1}{2}$.[4] If this decay depends on a weak interaction which does not conserve parity, then two particles can simultaneously be produced in either S- or in P-states. Invariance of the theory relative to combined inversion corresponds to the relation of phases of the S- and P-waves which is such that the probabilities of finding the particle C above and below the equatorial plane (perpendicular to the direction of spin of the particle A) are equal, so that there is no electrical dipole moment. However, the virtual particles C in the equatorial plane have a transverse polarization; their spin σ_C has a component directed along $[r \times \sigma_A]$. Thus, around the spin axis of A there is a ring of elementary magnets — virtual particles C with spin along the equator. The magnetic interaction, proportional to $(\sigma_C \cdot H)$ gives a term proportional to the integral $\oint H\, dl$, taken along the equator. Such an integral can be expressed in terms of curl H. It is relevant to remember Ioffe's work:[5] for a real decay, combined inversion gives an asymmetry in the direction of emission and a longitudinal polarization, whereas the second variant of Ioffe (invariance relative to charge conjugation) gives a symmetrical emission and transverse polarization of the emitted particles. In virtual decays, the correlation is the other way around; as noted by Ioffe, in the latter variant there can be a dipole moment, whereas in combined inversion there is no dipole moment, but, as can be seen from Ref. 4 and this note, there is a transverse polarization leading to the interaction $(\sigma \cdot \operatorname{curl} H)$. From the point of view of classification of magnetic properties of the particle, the interaction $(\sigma \cdot \operatorname{curl} H)$, obviously, does not correspond to any magnetic multipole (dipole, quadrupole, etc.); we will call it an "anapole." For an understanding of the anapole, transformation of the energy to the form $(\sigma \cdot j)$ is essential; the anapole interacts only with the current which flows into the point at which the particle is to be found. Consequently, the external field of the anapole is identically zero (more accurately — falls off just as the probability density in the cloud of virtual particles C falls off).

In this connection, the anapole is analogous to a spherical capacitor in which the field differs from zero only inside the capacitor. The difference from a capacitor comes from the fact that the anapole is a vector, has a definite direction (along the spin of the particle A considered), whereas a spherical capacitor is characterized by a scalar quantity.

A classical model of the anapole can be represented as a wire helix (solenoid) bent in a ring (toroid). The current flowing through the helix creates a magnetic field only inside the toroid. If the toroid is rigid, then no magnetic field produced by external currents can act on the toroid as a whole. However, if this wire toroid is immersed in a solution of electrolyte which fills also the space inside the solenoid and a current is passed through the electrolyte, then a moment of force, proportional to the sine of the angle between the toroid and the direction of the current in the electrolyte, will act on the toroid. This corresponds to an interaction energy $(\sigma \cdot j)$, since the axis of the toroid is directed along σ.

The anapole moment of elementary particles, i.e., the constant b, can be estimated by multiplying the magnetic moment by the Compton wavelength $\hbar/mc$ and by the square if the dimensionless constant of weak interaction f^2, i.e., is of order $10^{-26}\mu$, in so far as only the interaction in which parity is not conserved gives the anapole. It is possible that, for experimental observation, the interaction of the anapole, not with the current but with a varying electric field giving a moment of force $M = (4\pi b/c)[\sigma \times \dot{E}]$, is more important. However, in view of the smallness of b, at the present time such an experiment would not seem to be possible.

The anapole interaction is an example which directly refutes the assertion of V. G. Solov'ev,[6] according to which combined inversion and gauge invariance lead to conservation of spatial parity in electrodynamics.

After finishing this work, I learned that V. G. Vaks obtained independently results analogous to ours.

I should like to use this opportunity to thank B. L. Ioffe, A. S. Kompaneets (who proposed the name "anapole"), L. D. Landau, and Ia. A. Smorodinski for discusions.

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SPACE-ENERGY DISTRIBUTION OF NEUTRONS IN A HEAVY GASEOUS MODERATOR

M. V. KAZARNOVSKII

P. N. Lebedev Institute of Physics, Academy of Sciences, U.S.S.R.

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THE theory of neutron thermalization in a heavy (atomic weight $M \gg 1$) monoatomic gas with constant mean free path λ and constant neutron lifetime τ has been discussed in a number of papers.[1-3] However, the majority of the results refers to the energy distribution only. The space-energy distribution function has been found only in the region of relatively large energies.[2] In the case of weak absorption this problem can be solved exactly.

The equation for the space-energy distribution function[2] may be written as follows:

$$-\alpha\psi(\mathbf{r},x)+\beta x\nabla^2\psi(\mathbf{r},x)+(3-2x^2)\frac{\partial\psi(\mathbf{r},x)}{\partial x}+x\frac{\partial^2\psi(\mathbf{r},x)}{\partial x^2}=0,\qquad \alpha=(2M\lambda/\tau)\sqrt{m/2kT},\quad \beta=2M\lambda^2/3. \tag{1}$$

where x^2 is the neutron energy in units of kT (T — temperature of the moderator), $\psi(\mathbf{r}, x)$ is the space-energy distribution function divided by $x^2e^{-x^2}$, and m is the neutron mass.

For a moderator of finite dimensions one may obtain a solution of Eq. (1) in the form of an expansion in a complete set of orthonormal functions $R_l(\mathbf{r})$ of the Laplacian for the corresponding boundary value problem $[\nabla^2 R_l(\mathbf{r}) + \Omega_l R_l(\mathbf{r}) = 0]$, i.e.,

$$\psi(\mathbf{r},x)=\sum_l R_l(\mathbf{r})\,n_l(x). \tag{2}$$

then each of the functions $n_l(x)$ should satisfy the equation

$$x\,d^2n_l/dx^2+(3-2x^2)\,dn_l/dx-(\alpha+\beta x\Omega_l)\,n_l=0. \tag{3}$$

Making use of the requirement that $n_l(x)$ be finite as $x \to 0$, this equation may be transformed into an integral equation of the Volterra type

$$n_l(x)=C_l\Phi(a,2,x^2)+\alpha\int_0^x n_l(t)\,K(x,t)\,dt,$$
$$K(x,t)=\frac{1}{2}\Gamma(a)\,t^2e^{-t^2}\left[\Psi(a,2,t^2)\,\Phi(a,2,x^2)-\Phi(a,2,t^2)\,\Psi(a,2,x^2)\right], \tag{4}$$

the solution of which, as is well known, is of the form

$$n_l(x)=C_l\sum_{m=0}^{\infty}\alpha^m\varphi_m(x),\qquad \varphi_0(x)=\Phi(a,2,x^2);\quad \varphi_{m+1}(x)=\int_0^x\varphi_m(t)\,K(x,t)\,dt. \tag{5}$$

Here $\Phi(a, b, z)$ is confluent hypergeometric function and

$$\Psi(a,b,z)=\frac{1}{\Gamma(a)}\int_0^{\infty}e^{-zt}t^{a-1}(1+t)^{b-a-1}dt$$