Letters to the Editor

COSMOLOGY AND ELEMENTARY PARTICLES

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IN the construction of a theory of elementary particles the question also arises as to the connection between cosmological and local properties.[1] It is not excluded that phenomena on a cosmic scale, such as, for example, the expansion of our part of the universe with a preponderance of particles, not antiparticles, and other facts, are connected with properties of elementary particles.[2]

Thus, the well known ratio of the neutron and electron masses

$$m_N / m_e = g^2 / e^2, \qquad e^2 / 4\pi\hbar c = 1/137, \qquad g^2 / 4\pi\hbar c = 13.5 \tag{1}$$

allows us to introduce the idea of a universal mass

$$m_0 = m_N / (g^2 / 4\pi\hbar c) = m_e / (e^2 / 4\pi\hbar c) = 1.25 \cdot 10^{-25}\,\mathrm{g}. \tag{2}$$

Taken together, the quantities m_0, c, h form a complete set of fundamental constants with independent dimensions. By means of them we can introduce in addition to the masses m_N and m_e associated with the strong and electromagnetic interactions a mass m_G associated with the gravitational interaction. From dimensional considerations we have[1)]

$$m_G = G m_0^2 m_0 / \hbar c = 4 \cdot 10^{-66}\,\mathrm{g}, \qquad G = 6.67 \cdot 10^{-8}\ \mathrm{cm/g \cdot sec^2}. \tag{3}$$

The introduction of m_G brings with it the validity of the Klein-Gordon equation for the potentials $\eta_{\mu\nu}$ of a weak gravitational field:

$$\{\Box - (m_G c / \hbar)^2\}\eta_{\mu\nu} = 0. \tag{4}$$

The corresponding characteristic time $H_0 = m_G c^2/\hbar = 3.6 \times 10^{-18}\ \mathrm{sec}^{-1}$ is practically identical with the well known experimental value of the Hubble constant $H = 2.5 \times 10^{-18}\ \mathrm{sec}^{-1}$.

The fact that H_0 can be associated with the Hubble constant also follows from the empty-space Einstein equation with cosmological constant: $R_{\mu\nu} = -\lambda_0 g_{\mu\nu}$. From this we get for a small perturbation $\delta h_{\mu\nu} \equiv \eta_{\mu\nu}$ of a weak gravitational field ($h_{\mu\nu} = g_{\mu\nu} - \delta_{\mu\nu}$) the equation (4) with

$$(m_G c / \hbar)^2 = 2\lambda_0 / c^2. \tag{5}$$

If we use the idea that the cosmological constant λ_0 is connected with the Hubble constant by the relation[4] $\lambda_0 \approx H^2$, we find $H \approx H_0/2^{1/2} = 2.5 \times 10^{-18}\ \mathrm{sec}^{-1}$.

Because of the extreme importance of the problem, these curious relations between atomic and cosmological quantities should evidently be taken seriously.

I take occasion to express my gratitude to Prof. D. Ivanenko for a discussion of this question.

1)The question of the mass of the graviton is also discussed in papers by a number of authors.[3]

1 P. A. M. Dirac, Proc. Roy. Soc. **A165**, 199 (1938). J. A. Wheeler, Neutrinos, Gravitation, and Geometry, Rend. Scuola Int. Fisica "Enrico Fermi," Corso XI, Bologna, 1960, pp. 67-196.

2 D. Ivanenko, Introduction to Collection: Noveĭshee razvitie gravitatsii (Recent Developments in Gravitation), IIL, 1962.

3 F. M. Gomide, Nuovo cimento **30**, 672 (1963). K. P. Stanyukovich, Abstracts of the First Gravitational Conference, Moscow, 1961, page 103. A. Sapar, ibid., page 163.

4 G. C. McVittie, General Relativity and Cosmology, Chapman and Hill Ltd., London, 1956.

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THE POSSIBILITY OF DETERMINING RELAXATION RATES BY MEANS OF A HYDROGEN ATOM BEAM MASER

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THE hydrogen atom beam maser[1,2] is a highly stable standard of frequency. In addition, it can be utilized in various physical experiments: precise measurement of the magnitude of hyperfine splitting (hfs) of hydrogen, determination of the magnetic moment of the proton, the study of the interaction of atomic hydrogen with different gases, in particular, for the determination of the effective cross section of spin exchange during collision of two hydrogen atoms. For this it is necessary to determine the relaxation rate $\gamma = 1/\tau$, where τ is the lifetime of the atoms in the excited state. The relaxation rate $\gamma = \Sigma_i \gamma_i$ is defined as the sum of the relaxation rates of the various processes that lead to the loss of active atoms (flight of active particles from the vessel, destruction on the walls, relaxation due to magnetic field inhomogeneities, and re-orientation of the spins upon collision of two hydrogen atoms). The relaxation rate can be determined by several means, by investigating various characteristics of the maser. We present below some characteristics obtained in a hydrogen atom beam maser at the Lebedev Institute (λ = 21 cm). Figure 1 shows an oscillogram of the time dependence of the power of induced emission of an under-excited maser under the influence of a light pulse. The theoretical dependence of the power of the emission after the pulse is turned off has the form $P = P_0 e^{-2\gamma t}$ (P is the power of the emission). By selecting appropriate exponents, one can determine the relaxation rate (for the given photograph, $\gamma_0 = 3\ \text{sec}^{-1}$). It is possible to obtain information on the relaxation rate by studying the characteristics of the maser when it is running. Figure 2 shows the dependence of the power of the signal entering the input of the preamplifier, which is proportional to the output power of the maser, on the intensity of the beam of active atoms. The theoretical dependence has the form

$$P = \frac{h\nu Q}{2Q_c}\left[I - \frac{hV}{8\pi^2\mu_0 Q\eta}\left(\gamma_0 + A\frac{I}{V\gamma_1}\right)^2\right]. \qquad (1)$$

Here I is the intensity of the beam of active atoms, V is the volume of the vessel, Q is the Q of the resonator, Q_c is the Q of the coupling, μ_0 is the modulus of the matrix element of the dipole moment operator, η is a geometrical factor (magnitude 4—6), γ_0 is the relaxation rate independent of I, γ_1 is the relaxation due to escape of atoms from the vessel, and A is a constant characterizing the relaxation due to collision of two hydrogen atoms with spin exchange. If we put $\gamma_0 = 3\ \text{sec}^{-1}$ and the magnitude of critical current $I_{cr} = 5 \times 10^{12}$ particles/sec, then we obtain for the constant A a value $3 \times 10^{-10}\ \text{cm}^3/\text{sec-particle}$. Most of the error is associated with the estimate of I_{cr}. If we assume that we can err by a factor of two in evaluating I_{cr}, we obtain for A an interval of values $(1-6) \times 10^{-10}\ \text{cm}^3/\text{sec-particle}$.

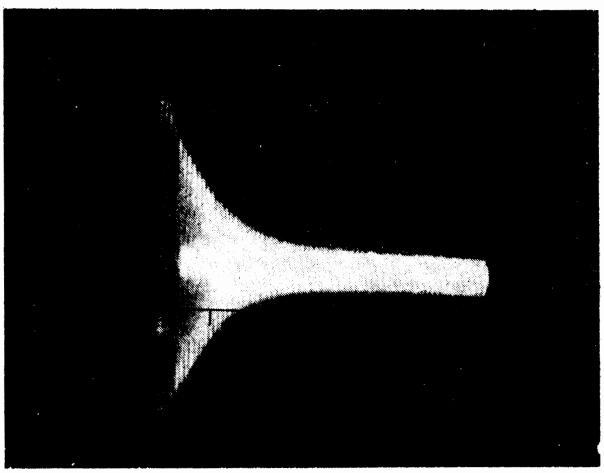

FIG. 1. Signal of induced emission of hydrogen atom after action of a light pulse. Repetition period of pulses 1.7 sec. Lifetime of excited atoms γ_0^{-1} = 0.3 sec.

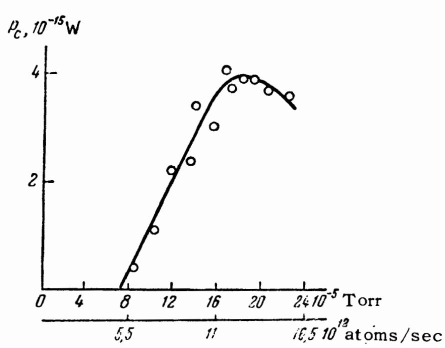

FIG. 2. Dependence of generated signal power on intensity of the atomic beam. Along the abscissa axis are plotted values of pressure in the section of the vacuum system closest to the source and the approximate values of the current of active particles entering the vessel.

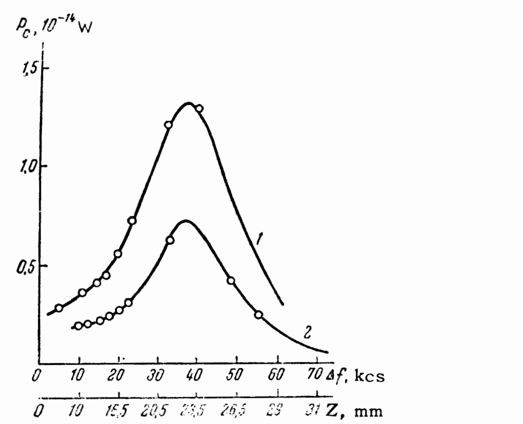

FIG. 3. Curve 1 — dependence of generated signal power on resonator tuning; along the x axis are plotted values of resonator tuning in kcs and the depth of penetration into the resonator of the 8 mm diameter tuning rod; 2 — amplitude of the 1420.4 Mcs signal traversing the resonator at various resonator tunings.

This number agrees with that given in the literature.[3] Other characteristics also give the possibility of determining the relaxation rate. Figure 3 shows the dependence of output power of the maser on resonator tuning (curve 1). Curve 2 (on a different scale) is the resonance curve of the resonator. The power of the generated signal falls by a half when the frequency of the resonator is detuned from the frequency of the line by about 15 kcs. At the same time the maser frequency changes by not more than 0.4—0.6 cps. Using the well-known formula for the pulling of the maser frequency by the resonator[3] we find that $\gamma_0 = \Delta\omega/2 \approx 2\ \sec^{-1}$, which is in approximate agreement with the results obtained from the oscillograms (Fig. 1).

[1] Goldenberg, Kleppner, and Ramsey, Phys. Rev. Letters **5**, 361 (1960).

[2] Kleppner, Goldenberg, and Ramsey, Appl. Optics **1**, 55 (1962).

[3] Kleppner, Goldenberg, and Ramsey, Phys. Rev. **126**, 603 (1962).

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NEUTRON SCATTERING BY SPIN WAVES IN IRON

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THE authors of [1,2] did not connect neutron scattering by spin waves with measurement of the polarization of the scattered neutrons, although the most characteristic feature of neutron scattering by spin waves is the neutron spin flip following excitation or absorption of the spin wave. In the present communication we present results of experiments on the scattering of polarized neutrons by single-crystal iron. We have investigated the excitation and absorption of spin waves for small-angle neutron scattering.

Since the energy of the spin wave excited in a ferromagnet placed in a magnetic field is equal to

$$\hbar\omega_k = Ak^2 + 2\mu_0 H$$

(where ω_k—frequency of the spin wave, μ_0—Bohr magneton, and A—constant determined by the exchange interaction), the following relation is satisfied in the case of small-angle neutron scattering

$$\hbar^2 \mathbf{p}_i^2 / 2m - \hbar^2 \mathbf{p}_f^2 / 2m = A(\mathbf{p}_i - \mathbf{p}_f)^2 + 2\mu_0 H,$$

where $\mathbf{p}_i$—neutron momentum prior to scattering and $\mathbf{p}_f$—neutron momentum after scattering. It follows from this relation that the scattering of neutrons by spin waves terminates at angles $\theta_0 \sim 1/\alpha$, where $\alpha = 2mA/\hbar^2$ (m—neutron mass).

The experiments were made with the equipment illustrated in Fig. 1. A quasi-monochromatic neutron beam ($\lambda \approx 2.9$ Å) is shaped by mirror 1, which limits the spectrum of neutrons from a reactor on the long-wave side, and a mirror-polarizer 2, which limits the spectrum on the short-wave side. The mirror 1 is produced by sputtering nickel on a plate of single-crystal quartz 0.4 mm thick. The total length of the mirror is 600 mm. The polarizer and analyzer were mirrors made by sputtering iron on TF-4 glass. The length of each mirror was 800 mm.

Such a mirror system makes it possible to obtain intense beams of quasi-monochromatic neutrons with polarization larger than 80% without beam broadening. The spin flip of the neutrons was with the aid of radio frequency coils 3 placed in a homogeneous magnetic field. By interconnecting these coils in different combinations it was possible to determine the polarization of the incident and scattered neutrons. The horizontal divergence of the incident and scattered beams was ± 2′, and the vertical divergence ± 20′. The sample was placed in a 26 kG field.

Figure 2 shows the measurement results. The data are given only for scattering through an angle larger than 6′, for at smaller angles the introduc-

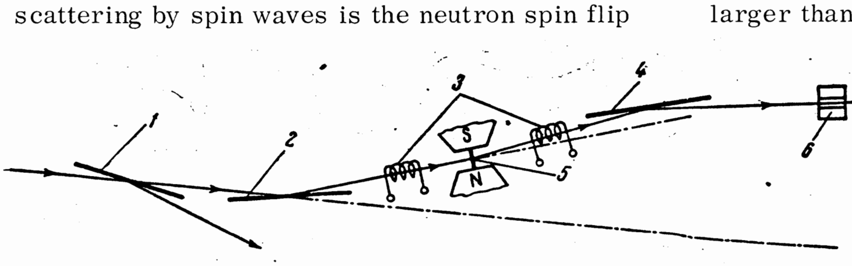

FIG. 1. Diagram of set-up: 1 – Nickel mirror on a quartz substrate, 2 – polarizer, 3 – radio-frequency coils for neutron spin flip, 4 – analyzer, 5 – sample, 6 – detector.