of ammonia shown at the bottom. We see that the reproducibility of the spectrum is high. The spectrum of Fig. 4 is in full accord with the lower spectrum of Fig. 2.

The results show that lasers with inhomogeneously broadened lines can be used as highly sensitive spectrographs. Indeed, to obtain the absorption spectrum of the third harmonic of the H-oscillation, say in NH_3 [5] or in HCN [4], cells several meters long are used at atmospheric pressure, and the spectrum of Fig. 4 reveals absorption lines at the edge of the rotational structure of the third harmonic of the fully-symmetrical vibration of ammonia, $\nu_1 = 3137$ cm^{-1}, at a layer thickness 0.3 cm. Such a spectrograph also has a high operating speed and is convenient for the investigation of fast processes.

If the absorption line changes the loss in the resonator by an amount $\Delta(1/T)$, then its registration requires a time t_r such that $\Delta(1/T)\cdot t_r \sim 1$. The nonlinearity of the spectrograph apparently does not prevent the performance of quantitative measurements. Its sensitivity can be varied at will by changing the temperature, and hence the homogeneous width γ and the geometry of the resonator and the ratio ST_0/I_0. To vary the working range, dyes can be used as the active media.

In conclusion, the authors are deeply grateful to M. D. Galanin for constant interest in the work and to T. P. Belikova for help with the work.

[1] V. S. Mashkevich, Zh. Eksp. Teor. Fiz. 53, 1003 (1967) [Sov. Phys.-JETP 26, 601 (1968)].
[2] V.I. Malyshev, A.V. Masalov, and A.A. Sychov, ZhETF Pis. Red. 11, 324 (1970) [JETP Lett. 11, 215 (1970)].
[3] M. N. Tolstoi and V. N. Shapovalov, Opt. spektrosk. 23, 648 (1967).
[4] G. Herzberg, Vibrational and Rotational Spectra of Polyatomic Molecules (Russ. transl.), IIL, 1949, pp. 320, 332, 485, 412.
[5] Sing-Hung Chao, Phys. Rev. 50, 27 (1936).

EQUILIBRIUM CONCENTRATION OF POSITRONS IN AN OPTICALLY THIN RELATIVISTIC PLASMA

G. S. Bisnovatyi-Kogan, Ya. B. Zel'dovich, and R. A. Syunyaev
Applied Mathematics Institute, USSR Academy of Sciences
Submitted 5 June 1970
ZhETF Pis. Red. 12, No. 2, 64 - 66 (20 July 1970)

In a plasma that is opaque to radiation, positron production begins at temperatures $kT \sim 0.1\ mc^2$. Very rapidly (at $kT \sim 0.4\ mc^2$, where m is the electron mass), the pair pressure becomes equal to the radiation pressure, and can greatly excbed the pressure of the initial electrons [1]. In a low-density plasma, when the radiation goes off freely, the positron concentration is determined by the equilibrium between the processes of pair production by collisions of e^- and e^+ with the nuclei and with one another (without participation of the photons), on the one hand, and the annihilation of the electrons and positrons (with emission of photons) on the other. No detailed equilibrium takes place and the equilibrium thermodynamic formulas are not valid. We present in this note the physical picture of the processes in such a plasma.

The main result is the absence of an equilibrium state at temperatures exceeding 20 MeV, thus establishing the upper limit of the temperature of an optically thin relativistic plasma.

Annihilation is a process of second order in the charge, and its cross section is of the order of

$$(\hbar/mc)^2\alpha^2 g(E/mc^2) = r_0^2\, g(E/mc^2),$$

where $\alpha = e^2/\hbar c = 1/137$ is the fine-structure constant, $r_0 = e^2/mc^2 = 2.8\times10^{-13}$ cm is the classical electron radius, and E is the pair energy in the c.m.s. When $E >> mc^2$ we have $g \sim E^{-2}$.

The number of annihilations per unit volume and per unit time, obtained by integrating over the maxwellian distributions of the electrons and positrons, is

$$A = \pi n_+ n_- c\, r_0^2\, \psi(\theta), \qquad \theta = kT/mc^2,$$

where

$$\psi(0) = 1 \quad \text{и} \quad \psi(\theta) \sim \theta^{-2} \text{ for } \theta >> 1.$$

Pair production in collision of charged particles is of fourth order in the charge, so that its cross section is of the order of

$$(\hbar/mc)^2\alpha^4 f(E/mc^2) = r_0^2\alpha^2 f(E/mc^2) \ .$$

After integrating over the Maxwellian distribution, we obtain the number of pair productions

$$B = \pi(n_p + n_+ + n_-)(n_+ + n_-)c\,r_0^2\alpha^2\phi(\theta)$$

$$\phi \sim \exp(-2/\theta) \text{ for } \theta < 1 \text{ and } \phi \sim \text{const for } 1 << \theta < M/m \ ,$$

so that the nuclei are nonrelativistic. We disregard here the slowly varying factors that are logarithmic in θ and the difference between the numerical coefficients for the pe^-, pe^+, e^-e^-, and e^-e^+ collisions.

Electroneutrality yields $n_p + n_+ = n_-$, so that finally we have

$$\frac{dn_+}{dt} = B - A = \pi c r_0^2 n_- n_+ \left[2\alpha^2\phi(\theta)\left(1 + \frac{n_-}{n_+}\right) - \psi(\theta)\right] .$$

We see therefore that in the stationary state each temperature corresponds to a definite ratio of the positrons to the electrons

$$\left.\frac{n_+}{n_-}\right|_{st} = 2\alpha^2\phi(\theta)\,[\psi(\theta) - 2\alpha^2\phi(\theta)]^{-1} .$$

An analogous situation arises in the determination of the degree of ionization of a low-density plasma in which the ionization is produced by electron impact and radiative recombination occurs (Elwert's formula).

Exact calculations using the formulas given in [2] yield the following expression for the positron concentration ($\theta > 1$, $\psi > 2\alpha^2\phi$, $n_+/n_- < 1$)

$$n_+ = \frac{56 n_p}{27\pi^2}\,\alpha^2\theta^2\ln^2(1+\theta) \approx 10^{-5} n_p\theta^2\ln^2(1+\theta) \ .$$

We note the difference from the case of complete statistical equilibrium, where the product n_+n_- is a constant on the order of $(mc/\hbar)^6\chi(\theta)$.

When $n << (mc/\hbar)^3 = 10^{33}$ cm^{-3}, in an optically thin and low-density plasma such as is encountered in astrophysics, the stationary positron concentration calculated above is quite small compared with the statistic-equilibrium positron concentration at the same temperature. New phenomena arise, in which $\alpha^2\Phi/(\psi - \alpha^2\phi)$ becomes equal to unity. The equality $n_+ = n_-$ sets in, with both n_+ and n_- tending to inifinity, so that there is no stationary solution. This takes place at $T \approx 40\ mc^2 \approx 20$ MeV. In the case of a cascade-like growth of the number of pairs $n_+ = n_-$ the kinetic equation takes the form

$$\frac{dn_+}{dt} = D(\theta)n_+^2 \ , \quad D = \pi c r_0^2\,[2\alpha^2\phi(\theta) - \psi(\theta)].$$

This equation would have n_+ go off to infinity within a finite time. An obvious limitation is the statistical equilibrium which would set in if the plasma were to become optically thick also with respect to bremsstrahlung absorption of the quanta, and not only with respect to the Compton scattering and pair production by the quanta. In the astrophysics of discrete radio sources, however, we are always exceedingly far from equlibrium, which would require a gigantic emission of energy.

In actual fact, the condition that the temperature be constant is violated, and the temperature adjusts itself to produce $D \equiv 0$, while the positron concentration corresponds to the energy pumping power.

We note finally that energywise pairproduction is always much less (by at least a factor α) than the bremsstrahlung. The unique role of pair production lies in the fact that in the presence of a magnetic field the positrons remain within the limits of the considered region of space, whereas the photons go off from the optically thin region ($\tau < 1$ with respect to Compton scattering). At an ultrarelativistic temperature, the bremsstrahlung photons cause pair photoproduction with a cross section smaller by a factor α than the photon-scattering cross section.

This factor α cancels out the ratio α^{-1} of the bremsstrahlung to pair production in collisions. The condition $\tau < 1$ suffices therefore for our results to be valid. When $\tau > 1$, so long as the bremsstrahlung absorption is small and there is no thermodynamic equilibrium, there also exists a temperature at which the stationarity vanishes; it is lower than $40mc^2$ and is close to mc^2 when $\tau \sim 10$.

Under astrophysical conditions, a relativistic plasma can consist for a long time of the same particles, and the energy loss is offset by pumping by radiation, shock waves, or alternating magnetic fields. In particular, such a situation can take place near radio-emitting regions of quasars and pulsars [3]. Another case is also possible, wherein fast particles are injected in the given region of space, and leave the region simultaneously with the energy loss.

Our calculations pertain only to a plasma with a lifetime larger than the time required to establish equilibrium. Observation of a plasma having an electron temperature (or effective energy) much higher than critical indicates that the plasma has stayed in such a state for a short time. A detailed article will be published in "Astronomicheskii zhurnal."

We are grateful to A. Z. Dolginov for a remark that stimultaed this research.

[1] L. D. Landau and E. M. Lifshitz, Statisticheskaya fizika (Statistical Physics), Nauka, 1964 [Addison-Wesley].
[2] A. I. Akhiezer and V. B. Berestetskii, Kvantovaya elektrodinamika (Quantum Electrodynamics), Fizmatgiz, 1959 [Wiley, 1965].
[3] E. V. Levich and R. A. Syunyaev, Radiofizika 13, No. 9 (1970)].

ATTENUATION OF LIGHT ABSORPTION IN ANTIFERROMAGNETIC $FeCO_3$ BY A MAGNETIC FIELD

V. V. Eremenko, Yu. G. Litvinenko, and V. I. Myatlik
Physico-technical Institute of Low Temperatures, Ukrainian Academy of Sciences
Submitted 8 June 1970
ZhETF Pis. Red. 12, No. 2, 66 - 69 (20 July 1970)

It was shown recently that the main electric-dipole absorption of light in antiferromagnetic crystals is due to exciton-magnon optical transitions [1 - 4]. These transitions constitute a particular case of "double" transitions, the general theory of which was constructed by Dexter [5].

In an antiferromagnetic crystal, the "double" exciton-magnon transition is much less intense than the "single" pure-exciton transition. Inasmuch as exciton-magnon electric-dipole absorption is peculiar to antiferromagnets, one can expect light absorption in the crystal to weaken when the antiferromagnetic structure is destroyed. The present paper is devoted to an experimental observation of this effect.

We chose for the investigation siderite - $FeCO_3$. This crystal has a rhombohedral structure and a magnetic anisotropy of the "easy axis" type. Below the temperature $T_N = 32°K$, siderite goes over into an antiferromagnetic state , with the magnetic moments of the sublattices directed along the threefold axis C_3. In a magnetic field H parallel to C_3 with intensity $H \geq 180$ kOe, the magnetic moments of both sublattices of siderite become practically parallel to each other and to the external magnetic field H. In any case, the measured magnetic moment of the crystal in so strong a field is close to the calculated summary magnetic moment of both sublattices when the latter are parallel [6]. It was precisely this circumstance that governed the choice of siderite as the object of the investigation.

The experimental procedure was described earlier [7]. The linear dispersion of the spectral instrument (DFS-13) is sufficiently large, 4 Å/mm. The sample temperature was 20.4 or