Table II

Values of the Rydberg constants R, the line half-widths, and the distances $\Delta\nu$ between the limits of the exciton series in Cu_2O and Ag_2O

Substance	Series	R, cm^{-1}	Line half-width, cm^{-1}	$\Delta\nu$, cm^{-1}
Cu_2O $T = 4.2°K$	Yellow	780	7	1060
	Green	1200	30	
Ag_2O $T \cong 20°K$	Infrared	800	10	-
	Red	1300	40	1670

This fact shows that in Ag_2O, just as in Cu_2O, the two series are the result of spin-orbit splitting, and thus confirms Elliott's point of view concerning the origin of the "yellow" and "green" series in Cu_2O.

[1] E. F. Gross and N. A. Karryev, DAN SSSR 84, 261 and 471 (1952); E. F. Gross and B. P. Zakharchenya, DAN SSSR 90, 745 (1953).

[2] E. F. Gross and Chang Kuang-yin, FTT 4, 261 (1962), Soviet Phys. Solid State 4, 186 (1962).

[3] R. J. Elliott, Phys. Rev. 103, 1384 (1957); 124, 340 (1961).

[4] P. P. Pavinskii and A. G. Zhilich, Vestnik, Leningrad State Univ., Phys.-Chem. Series, No. 4, 50 (1957).

[5] L. V. Gregor and R. S. Pitzer, Aner. Chem. Soc. 84, 2664 (1962).

[6] Ch. Moore, Atomic Energy Levels 2 (1952); 3 (1958) (Washington, NBS Circ. 467).

1) Owing to the imperfection of the samples, we have not yet succeeded in observing in Ag_2O the line corresponding to n = 1 in the "yellow" series of Cu_2O.

ANOMALIES OF POSITRON ANNIHILATION IN IONIC CRYSTALS

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Several papers by Italian scientists report interesting anomalies of positron annihilation in ionic crystals.

It has been found that magnetic quenching of ortho-positronium is anomalously weak in KCl [1], normal in polymers [2,3], and anomalously strong in water [2,4]. This means that the magnetic-quenching parameter Q is smaller in KCl and larger in water than the theoretical value

$$Q_0 = (2\mu_0 H/\Delta W_0)^2 \frac{\tau}{\tau_S^0}, \qquad (1)$$

where μ_0 is the magnetic moment of the electron,

$$\Delta W_0 = \frac{56}{3} \pi\mu_0^2 |\Psi_0(0)|^2$$

is the excess of the energy of the triplet positronium ($1^3 S_1$) over the singlet ($1^1 S_0$),

$$\tau_S = [4\pi r_0^2 c |\Psi(0)|^2]^{-1} = 1.25 \times 10^{-10} \text{ sec}$$

is the proper lifetime of the singlet positronium, τ is the experimentally-measured lifetime of the triplet positronium, determined in the condensed phase by the pick-off annihilation ($\tau = \tau_T^0 = 1115\tau_S^0$ for free positronium and in the gas phase), r_0 is the classical radius of the electron, and $|\Psi(0)|^2$ is the density of the wave functions of the electron and positron in the region where they overlap in the positronium atom.

On the other hand, it has been found [5-7] that the probability of 3γ annihilation in many ionic crystals (including the aforementioned KCl, but to a particularly strong degree in BeO) is much higher than the value $P_{3\gamma} = 0.27\%$ expected for the pick-off annihilation.

Since

$$P_{3\gamma} = I_2 \frac{\tau}{\tau_T^0} + (1 - \frac{4}{3} I_2) \frac{1}{372}, \qquad (2)$$

where I_2 is the experimentally observed intensity of the long-lived annihilation component, and its lifetime τ is also an experimentally-obtained quantity, we can attribute the growth of $P_{3\gamma}$ only to the decrease of τ_T^0 (meaning also τ_S^0).

To explain the anomalously strong magnetic quenching in water, Fabri et al. [3,4] proposed to use the purely empirical $\Delta W = 5 \times 10^{-4}$ eV instead of the theoretical $\Delta W_0 = 8.34 \times 10^{-4}$ eV for free positronium [1].

The anomalously weak magnetic quenching and the increase in the 3γ-annihilation probability in ionic crystals have not yet been explained at all.

It is possible to interpret these anomalies by regarding positronium in ionic crystals as a unique type of exciton consisting of two quasiparticles bound in a Coulomb field $U = -e^2/\epsilon r$ (where ϵ is the optical dielectric constant, r the distance, and e the charge), and having effective masses m_- (electron) and m_+ (positron).

Within the phenomenological exciton model

$$|\Psi(0)|^2 = |\Psi(0)|_0^2 \frac{1}{\epsilon^2} \left[\frac{M}{M_0}\right]^3, \qquad (3)$$

where $M_0 = m_0/2$ is the reduced mass of the free positronium, m_0 is the electron mass, and $M = m_+m_-/(m_+ + m_-)$ the reduced mass of its exciton state in the condensed phase.

In addition, the quantity μ_0^2 should be replaced for such an exciton state by the product $\mu_+\mu_- = \mu_0^2(m_0/m_-)(m_0/m_+)$.

As a result we obtain for the magnetic quenching parameter Q

$$Q = Q_0 \frac{\mu_0^2 |\Psi(0)|^2}{\mu_- \mu_+ |\Psi(0)|^2} = Q_0 \epsilon^3 \frac{m_0 (m_- + m_+)^3}{8 m_-^2 m_+^2} , \tag{4}$$

and when $m_- = m_+ = m$

$$Q = Q_0 \epsilon^3 \frac{m_0}{m} , \tag{5}$$

i.e., the effective field acting on the positronium in the condensed phase is

$$H_{eff} = H \left[\epsilon^3 \frac{m_0}{m} \right]^{\frac{1}{2}} . \tag{6}$$

Further, we obtain on the basis of (2) for the 3γ-annihilation probability

$$P_{3\gamma} = I_2 \frac{\tau_0}{\tau_T} \frac{1}{\epsilon^3} \left[\frac{M}{M_0} \right]^3 + \left[1 - \frac{4}{3} I_2 \right] \frac{1}{372} . \tag{7}$$

To estimate the compatibility of the experimental data with the concepts employed here, we can put $\epsilon \approx 1$, just as done by Nosov and Yakovleva [8,9] for muonium.

It then follows from the experimental data on magnetic quenching [1] that $m/m_0 \approx 4 \pm 2$ for KCl. From data on 3γ annihilation [5-7] we can conclude that $M/M_0 \approx 3$ for BeO ($P_{3\gamma}$ increases by a factor of 23 (!) compared with that expected for pick-off annihilation).

We present below the values given by Pekar [10] for the effective masses of the electron in some ionic crystals:

Crystal	NaCl	NaBr	NaI	KCl	KBr	KI	RbCl	RbBr	RbI
$\frac{m_-}{m_0}$	2.78	2.96	3.25	1.85	1.87	2.11	1.78	1.70	1.89

The effective mass of the positron in ionic crystals is unknown, but in liquid sodium, for example, $m_+ = 1.9 m_0$ [11].

Thus, we have a qualitative confirmation of the proposed treatment of positron annihilation anomalies in ionic crystals. For a quantitative check we must compare systematically, for the same substances, the data on magnetic quenching (which so far has been studied only for KCl, and with accuracy insufficient to determine H_{eff} at that), and the probability of 3γ positron annihilation.

[1] A. Bisi, A. Fiorentini, and L. Zappa, Phys. Rev. 134, A328 (1964).

[2] G. Iaci, I. F. Quercia, and E. Turrisi, Nuovo Cimento 24, 746 (1962).

[3] G. Fabri, G. Poletti, and G. Randone, Phys. Rev. 135, A80 (1964).

[4] G. Fabri, E. Germagnoli, I. F. Quercia, and E. Turrisi, Nuovo Cimento 30, 21 (1963).

[5] A. Gainotti, E. Germagnoli, G. Schianchi, and L. Zecchina, ibid. 32, 880 (1964).

[6] A. Gainotti, E. Germagnoli, G. Schianchi, and L. Zecchina, Phys. Lett. 13, 9 (1964).

[7] G. Bussolati and L. Zappa, Phys. Rev. 136, A657 (1964).
[8] V. G. Nosov and I. V. Yakovleva, JETP 43, 1750 (1964), Soviet Phys. JETP 16, 1236 (1963).
[9] V. G. Nosov and I. V. Yakovleva, Nucl. Phys. 68, 609 (1965).
[10] S. I. Pekar, Issledovaniya po elektronnoi teorii kristallov (Research on the Electron Theory of Crystals), GITTL, 1951.
[11] A. T. Stewart and J. Shand, Phys. Rev. Lett. 16, 67 (1966).

1) It would be necessary here to allow also for the change in τ_S. It is easy to verify that for a specified electron and positron mass we obtain $\tau_S \Delta W = (\hbar c/e^2)\hbar \simeq 137\hbar = \text{const.}$ for any value of $|\Psi(0)|^2$.

INTERFERENCE OF DIFFERENT FREQUENCIES IN BREMSSTRAHLUNG

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We consider in the classical-electrodynamics approach the radiation produced by collision of a charge moving in a straight line before and after the collision (Fig. 1).

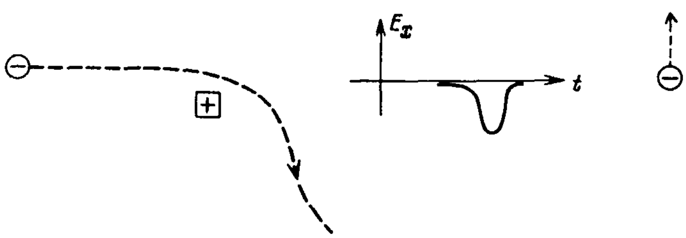

Fig. 1

The charge experiences an acceleration pulse whose time dependence is close to a delta-function. In accord with the Lienard-Wiechert formulas, the electric field E of the resultant electromagnetic radiation is proportional to the acceleration. Consequently, $\vec{E}(t)$ has at a distant point the form shown in the middle of Fig. 1. $\vec{E}$ is directed downward (Fig. 1 shows a moving negative charge), and E(t) is similar to $r^{-1}\delta(t - t_0 - r/c)$, where t_0 is the instant of deflection of the radiating particle. The purpose of the present note is to call attention to the fact that E does not reverse sign in the wave, with $\vec{E}$ either zero or directed downward, i.e., there are no "oscillations" in the proper sense of the word.

A pulse of this type can, naturally, be expanded in a Fourier integral, i.e., represented as a superposition of sinusoidal (alternating-sign) electromagnetic waves of different frequencies. However, if we specify only the spectral density (the amplitude modulus squared) of the expansion as a function $I(\omega)$, the we lose the very property causing the unique shape of the pulse (the lack of an alternating-sign field). The shape of the pulse depends essentially on the phase relations between the waves (the Fourier components) of different fre-