This, therefore, signifies isotropy of both components for the resonant radiation in accordance with the abovementioned work of Devons and Hine and McDaniel and Stearns.

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Phosphorescent Effects with High Energy Radiation*

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THE fluorescence and phosphorescence of sodium chloride crystals have previously been investigated by Glasser and Beaseley[1,2] and Mandeville and Albrecht.[3] The very interesting observations of Glasser and Beaseley on phosphorescence and light stimulation have been extended and investigated more quantitatively. Our investigations have been conducted on NaCl crystals activated with 1 percent AgCl provided for us by the courtesy of the Harshaw Chemical Company. An essential difference between our crystals and theirs may be a much greater light efficiency, since under gamma-irradiation our activated crystals were as efficient as anthracene in our standard integrating intensity arrangement with the 1P28 photomultiplier,[4] and since after light stimulation they are easily visible to dark adapted eyes after first being subjected to sufficient high energy radiation.

(1) Under gamma-irradiation the crystal does not reach its maximum light intensity at once, but the fluorescent intensity shows a slow increase of about 25 percent in one hour and then remains essentially at a steady value. The emission spectrum obtained for gamma-excitation consists of 2 bands: one in the ultraviolet from about 2350–2600A and another from about 3200–4500A.

(2) Upon removal of the gamma-source, the luminescence of the crystal drops immediately to about 1/4 to 1/2 of the original intensity and then decays rather slowly. This immediate drop and the following decay diminish with increasing total of gamma-irradiation (doses). With a dose of 60 roentgens, for example, after two days, more than 5 percent of the original fluorescent intensity still remained.

(3) Irradiating the crystals with visible or near ultraviolet light (about 3600A) produced no luminescence if the crystals were not first exposed to high energy radiation. However, if the crystals are first excited by high energy radiation and then exposed to visible or near ultraviolet light (light stimulation), a tremendous increase in luminescent light output is observed; this is the case even after the original high energy induced luminescence has decayed to a very low level.

(4) The luminescent output, for the same amount of near ultraviolet radiation, was found to be roughly proportional to the total amount of gamma-excitation (doses) received by the crystal.

(5) A variation of the rate of excitation by a factor of 100 for a total gamma-excitation of 1 roentgen produced no difference in luminescent output after ultraviolet irradiation of one minute.

(6) A dose of 10 milliroentgens could easily be detected by light stimulation within one hour after gamma-irradiation and was still barely detectable after one day.

(7) A dose of 1 roentgen could be detected visibly with dark-adapted eyes and an ultraviolet intensifying screen. Only about a quarter of the total emitted light is visible.

(8) After a dose of about 500 roentgens over 20 hours of irradiation, stimulation by a tungsten lamp produced a light intensity 450 times larger than the original light intensity after the immediate drop in intensity. The stimulation was applied one hour after removal of the gamma-source.

(9) The light-stimulated luminescence also decays slowly and amounts to about 10 percent after 5 minutes; it does not seem to depend on the gamma-dose. It is faster than the phosphorescence decay after direct excitation by high energy radiation, especially when high gamma-doses are applied.

(10) Under continuous light stimulation, with wavelengths up to about 7500A, the luminescent intensity rises, goes through a maximum, and then slowly decays depending on the strength and spectral distribution of the stimulating light. Most effective light stimulation occurs around 3600A. A certain difficulty in removing the last traces of gamma-excitation exists. Strong and extended light irradiation must be applied.

(11) Light stimulation can be applied intermittently with ever-decreasing amplitudes of luminescence.

(12) The process of luminescent stimulation by light can be initiated after delays of three days and very likely much longer. The intensities obtained after such long delays with strong excitation were essentially the same as after short delays.

(13) Excitation with alpha-particles similarly gave a large luminescent output. The decay was, however, considerably faster after the removal of the exciting alpha-source than after gamma-irradiation. After use of a 5-millicurie alpha-source, there was an almost immediate drop to about 10 percent of the original value and then a further drop in 10 minutes of 85 percent. The light stimulating effect after alphas was not as high as that after gamma-irradiation, probably as a consequence of the alpha-particle irradiation being a surface effect and causing an increased density of excitation.

(14) Under fast electron bombardment strong phosphorescence was also observed. The effects were very similar to those after gamma-irradiation. Three days after the removal of the beta-source, the intensity was still several percent of the original decay luminescence. If after this length of time the crystal was irradiated with light, the intensity was of the same order as the initial luminescence.

These properties make activated NaCl crystals very suitable for detection of all types of high energy radiation. Experiments with cosmic rays were not yet conclusive, since crystals which were completely de-excited show a small increase in luminescence after being in darkness for several days. Whether this effect is due to cosmic rays or to a natural recovery of the crystal has not been yet ascertained.

A rough estimate of the amount of stored energy that can be expelled by light stimulation shows that about 20 percent of the total energy which can be emitted as light is stored and can be released by the light stimulation.

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Pressure-Induced Absorption in Hydrogen

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CRAWFORD, *et al.*[1-3] observed in compressed hydrogen and hydrogen foreign gas mixtures an absorption at the frequency of the usually forbidden 0—1 vibrational band of hydrogen. From the pressure dependence of this absorption they concluded that molecular distortions induced during binary collisions are responsible for this pressure activation of the vibrational band. Detailed calculations have now been made of this pressure-induced absorption in H_2. It is assumed that the absorption coefficient may be obtained by first calculating the absorption due to one interacting pair of molecules (1 and 2) at fixed distance R, and then adding the contributions of all pairs of molecules. The absorption due to a pair 1,2 is obtained by considering $0-1$ vibrational transitions in molecule 1 or 2, accompanied by rotational transitions in either or both of the molecules. These radiational transitions result from the dipole moment arising from the mutual distortion of 1 and 2 which is the sum of:

(i) The distortion due to the overlapping of the wave functions of 1 and 2; this distortion, which decreases exponentially with R, has been calculated using a variational method and Rosen type wave functions.[4] This effect is primarily responsible for the Q-branch ($\Delta J=0$), contributing but slightly to the S- and O-branches ($\Delta J=+2, -2$).

(ii) The distortion due to the permanent quadrupole moments of 1 and 2, which is present even when 1 and 2 do not overlap and which decreases as R^{-4}. This effect is primarily responsible for the S-branch. Let Q^0 and α^0 be the quadrupole moment and polarizability of the H_2 molecule in its equilibrium position, and Q' and α' the derivatives with respect to the internuclear distance r. Then the contribution to the absorption coefficient due to effect (ii) contains two terms, proportional to $(Q^0\alpha')^2$ and $(Q'\alpha^0)^2$, respectively. The first of these two terms has also been considered by Mizushima in his examination of the absorption in oxygen.[5,6] If we consider $0-1$ vibrational transitions taking place in molecule 1, then this term corresponds to the Q^0 of molecule 2 polarizing molecule 1, giving it a dipole moment which depends on r_1 because α_1 depends on r_1 (i.e., on α'). The second term proportional to $(Q'\alpha^0)^2$, however, is as important as the first one, and results from the fact that the Q of molecule 1 induces a dipole in molecule 2 which also depends on r_1 because Q_1 depends on r_1 (i.e., on Q').

The total dipole moment of a pair of molecules at a fixed distance R and mutual orientations ω_1 and ω_2 ($\omega=\vartheta, \varphi$ where ϑ, φ are polar angles with R as polar axis), produced by the effects (i) and (ii) can be expanded in a Taylor series in the internuclear distances r_1 and r_2 about their equilibrium values $r_1{}^0$ and $r_2{}^0$:

$$\mu(R, r_1, r_2, \omega_1, \omega_2)=\mu^0(R, \omega_1, \omega_2)+(r_1-r_1{}^0)\cdot\mu_1'(R, \omega_1, \omega_2) \\ +(r_2-r_2{}^0)\cdot\mu_2'(R, \omega_1, \omega_2)+\cdots. \quad (1)$$

The first term in (1) gives no contribution to the $0-1$ vibrational transition elements, and the second and third terms give identical contributions to the absorption coefficient. The contribution to the total absorption coefficient of one pair of molecules undergoing vibrational transitions $0-1$ and rotational transitions from $\rho(=J_1, m_1, J_2, m_2)$ to ρ' is:

$$a_{\rho\rho'}(R)=[4\pi(\nu/\nu_0)/3m_{\mathrm{H}}c]P_\rho|(\mu_1')_{\rho\rho'}|^2 \quad (2)$$

in which $\nu=\nu_0+(E_{\rho'}-E_\rho)/h$, ν_0=fundamental vibration frequency, m_{H}=mass of H atom, and P_ρ is essentially the population of the initial rotational state ρ. $(\mu_1')_{\rho\rho'}$ is still a function of R. Adding the contributions of all pairs of molecules gives:

$$A_{\rho\rho'}=(N^2/2V)[4\pi(\nu/\nu_0)/3m_Hc]P_\rho \\ \times\int_0^\infty |(\mu_1')_{\rho\rho'}|^2\exp[-\varphi(R)/kT]4\pi R^2dR \quad (3)$$

where for $\varphi(R)$ we have used the average experimental intermolecular field from second virial coefficients.[7] N is the number of molecules, V the volume.

TABLE I. Values of $A_{\rho\rho'}$.

Branch	H_2-H_2	H_2-He
$O(3)$	0.067	0.013
$O(2)$	0.072	0.014
Q	2.74	2.76
$S(0)$	0.466	0.089
$S(1)$	1.51	0.289
$S(2)$	0.241	0.047
$S(3)$	0.181	0.035
$A_{\mathrm{theor.}}$(total)	5.28	3.25
$A_{\mathrm{exp.}}$(total)	10.5	7.44

TABLE II. Ratio of intensities, $Q:S:O$.

	H_2-H_2	H_2-He
Theoretical	1:0.87:0.05	1:0.17:0.01
Experimental	1:0.8 :0.04	1:0.2 :0.02

In the accompanying table is given the total calculated absorption for pure H_2, in (cm^{-1} sec^{-1})(per molecule)(per molecule per cm^3)$\times10^{32}$. The enhancement of the H_2-absorption due to the adding of He has also been calculated, and the results for this enhancement are given in Table I, in (cm^{-1} sec^{-1})(per molecule H_2)(per atom He per cm^3)$\times10^{32}$. From this table it may be seen that the calculated values of $A_{\rho\rho'}$ are too small but are of the right order of magnitude. The discrepancy may easily result from our use of over-simplified wave functions and variational methods in the calculation of the distortions due to effects (i) and (ii). Such simplifications are necessary, however, in order to avoid unreasonably complicated calculations.

The calculated relative intensities of the Q-, S-, and O-branches are in close agreement with the corresponding experimental values, as is shown in Table II. The experimental ratios have been estimated from the graphs given by Crawford, *et al.*[3]

A detailed account of this work will appear in *Physica*. We wish to thank Professor J. de Boer for suggesting this problem and for many helpful discussions. One of the authors (RBB) wishes to acknowledge the opportunity for foreign study made possible by the Fulbright Exchange Program.

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Dipolar Domains in Paramagnetic Crystals at Low Temperatures

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A THEORY of dipolar paramagnetic domains can be constructed similar to the theory[1] of ferromagnetic domains. At very low temperatures ($T\ll T_c\approx\mu^2/ka^3\approx0.1$°K), according to the classical theory of dipolar interactions,[2,3] crystals bearing spins on b.c.c. and f.c.c. lattices will be magnetically saturated, if demagnetizing effects are neglected. Domains may then form to lower the demagnetization energy of a bounded crystal. Previous workers overlooked the possibility of domain formation, and some of their conclusions must accordingly be modified. The present discussion is limited to 0°K.

Wall energy.—An upper limit to the surface energy density σ of the boundary between domains saturated in opposite directions is given by supposing the transition occurs abruptly, between two adjacent planes of dipoles. Then $\sigma\approx(\mu/a^3)\mu(1/a^2)\approx M_s{}^2a$; for a saturation magnetization $M_s\approx500$ and lattice constant $a\approx4\times10^{-8}$ cm, $\sigma\approx10^{-2}$ erg/cm^2. The form of the estimate may be checked against the results of Luttinger and Tisza for alternating planes of dipoles.

Wall thickness.—Measured in lattice constants, the thickness of the transition layer is, according to FD Eq. (3.2.6), $\approx$(dipolar energy per ion/anisotropy energy per ion)$^{\frac{1}{2}}\approx1$, since the anisotropy energy is $\approx\mu^2/a^3$ as discussed below.

Dipolar energy.—Within a domain, or in an infinitely long specimen, the classical dipolar energy density is calculated from the Lorentz field and is $(2\pi/3)M_s{}^2\approx5\times10^5$ ergs/cc.

Anisotropy energy.—Classically there is no anisotropy energy in a saturated cubic crystal, but in quantum mechanics the zero-point motion prevents complete saturation and anisotropy arises