HARD RADIATION FROM SOLIDS FAILING IN SHEAR

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It is known that mechanical failure of solids can be accompanied by acoustic effects, glow, and scattering of the material of a sample subjected to stresses and strains on the order of several per cent or even tenths of one per cent respectively of the elastic moduli (Young's or shear) and of the initial geometric parameters.

Many investigators have attempted to determine experimentally the rheological functions and structure changes under high pressures and high shear deformations (e.g., **Bridgman** [1]), but paid no attention to optical phenomena [4].

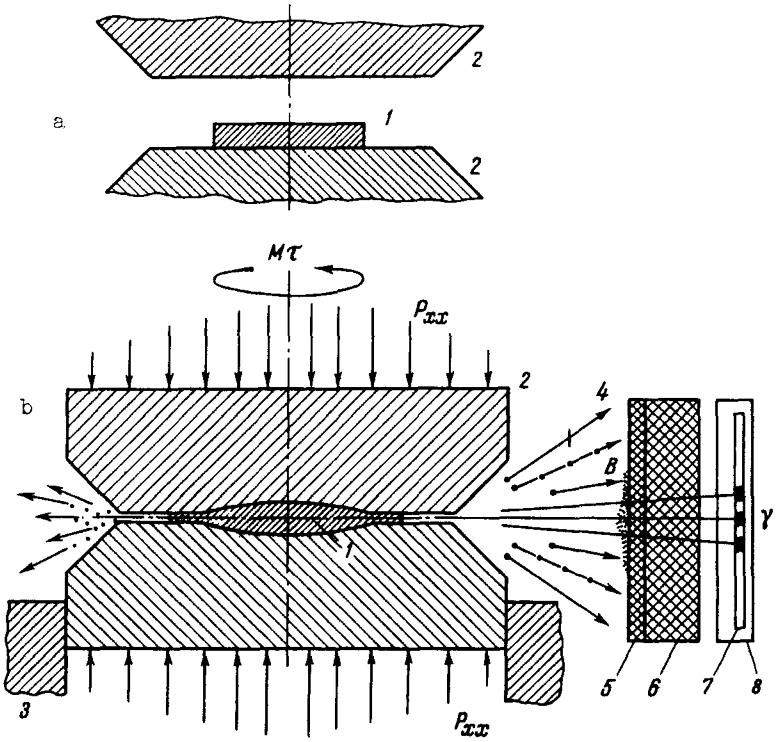

Fig. 1. Diagram of experiment on the failure of a solid in shear, with hard radiation: 1 - Tested sample, 2 - plungers, 3 - plunger fitting, 4 - emitted light, 5,6,7 - screens, 8 - cassette, P_{xx} - axial load on plungers, M_τ - torque producing tangential stresses τ in the sample, B - scattered matter, γ - hard radiation.

It was of considerable interest to investigate damage produced by an appreciable shear deformation and to analyze the effects accompanying this damage. Our experiments were based on the hypothesis that the failure in shear begins with formation of minute internal cavities, and that the cavity formation process, and by the same token the failure, can be countered by a hydrostatic compression of appreciable magnitude. In other words, we assume that failure under hydrostatic pressure occurs only after the onset of appreciable shear strains, and that the kinetics of the process would be different than in the absence of large hydrostatic pressure.

To check on this proposition, a solid sample in the form of a cylinder 1 of ~10 mm diameter and ~2 mm height was located (Figs. 1a and 3) on the center of two coaxial plungers 2 made of hard-alloy (tungsten-cobalt carbide) plates. The latter were chosen for rigidity, their Young's modulus being 3 - 4 times larger than that of steel (i.e., (60 - 80) x 10^{11} dyn/cm^2). The tested substances were nonexplosive various polycrystalline dielectrics and semiconductors (marble, basalt, coal, etc.) both with native (undisturbed) structure and in the form of tablets pressed from powders of the inorganic or organic material.

The plungers were mounted in a fitting 3 placed between the plates of a vertical press. The press brought together the plungers and they in turn compressed the samples. At first the samples were damaged partially along the edges, after which they pressed into the working surface of the plungers, in which they produced a lentil-shaped cavity. The press forces ΣP_{xx} were such that a hydrostatic pressure on the order of 10^{11} dyn/cm^2 was produced in these cavities.

At a constant vertical force of the press, additional tangential stresses τ (due to a torque M_τ) of considerable magnitude, on the order of 5 x 10^{11} dyn/cm^2, were produced in the sample by the aforementioned fitting. Under the action of these stresses, the sample experienced large plastic shear deformation, up to several units ($\tan \gamma = 1 - 10$) in its peripheral region (disregarding possible slippage). At a certain value of shear deformation, an explosion occurred, i.e., a sound effect similar to gunshot, accompanied by scattering of some finely dispersed test material. Only a small fraction, amounting to about 0.01 - 0.1 g, participated in the explosion.

The axial load and the hydrostatic pressure on the tested sample were not critical quantities (as in Bridgman's experiments [1]), since they could be varied over a wide range, for example from 50 to 500% of the forces at which an explosion was produced in conjunction with the shear in the preceding experiment. At the same time, an explosion was produced whenever the tangential stress reached a definite value, i.e., the tangential deformation was a critical quantity under certain conditions. The force of the explosion and the critical tangential stresses increased with the axial load on the tested object. The angles of rotation of the upper and lower plungers fluctuated statistically between 10 and 40°, i.e., they were appreciable albeit random. No noticeable dependence was observed on the kind of tested material, on the magnitude of the hydrostatic compression, or on the tangential stresses and other factors.

During the explosion, the tested material was scattered radially in the form of finely dispersed dust and penetrated with high force into an annular paper screen 5, mounted on a rigid screen 6, puncturing the paper screen in a number of places. The rigid screen was made of 4 mm Plexiglas in the form of an almost-closed ring. In the absence of the screens, the dispersed matter was scattered to distances on the order of 500 cm.

If the explosion is produced in a darkened room, strong blue-violet glow 4 is always observed in an annular region around the plungers; no noticeable visual change is observed in the color when the substance or the load is changed. A photographic screen in the form of a cassette (envelope) 8 of light-tight paper and photographic film 7 were placed behind the rigid screen 6. In all experiments, hard radiation was observed, producing a photographic image in the film after traversing an air layer on the order of 8 cm, several (2 - 4) thicknesses of paper on the order of 0.05 - 0.1 mm, and a 4-mm layer of Plexiglas. The exposure was produced by simultaneous pulses at a number of distinct locations (Fig. 2). The limited regions and the large differences in the exposure intensity indicate that the excitations are localized and that the radiation has narrow directivity.

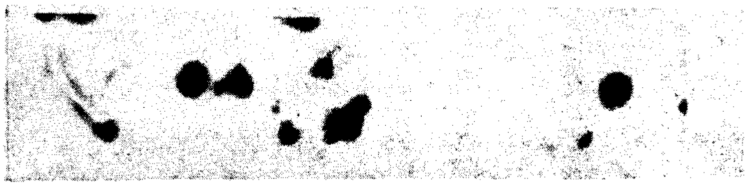

Fig. 2. Exposure of photographic film to hard radiation during shear failure (magnification 3×).

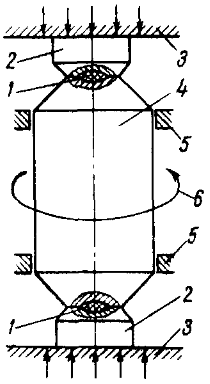

Fig. 3. Kinematic diagram of fitting used to produce shear and "uniaxial" compression: 1 - Test sample, 2 - static plungers, 3 - plates of press, 4 - paired rotor-plunger, 5 - rotor guides, 6 - rotor torque direction.

It is probable that the hard radiation emerges only from those internal cavities in which explosive chain reactions accompanied by radiation are produced by virtue of the inhomogeneity of the unstressed state; this radiation is emitted in distinct directions from the cavities that are opened by the explosion. Several such cavities are produced. All have a nearly-circular shape. Their diameters fall in three groups. Microphotography (with an MF-4) has shown that the photographic density is not smaller than two different values, $J_1 = \log 88$ and $J_2 = \log 40$.

A tentative estimate based on the (narrow-beam) mass absorption coefficients of x rays and γ rays above the K absorption edge, for different plastics [2], showed that hard radiation was produced, with wavelength 0.5 Å (i.e., ≈25 keV), as well as harder radiation. In other words, we observed in the explosion not only short-wave visible (blue-violet) radiation, but also hard radiation.

The foregoing experimental facts show that we are dealing here with a hitherto uninvestigated process of failure under strong tangential stresses, produced as a result of adhesion of the tested material with the surfaces of the plungers and as a result of prevention (by high hydrostatic pressure) of formation of internal cavities. It is probable that the process consists essentially of instantaneous release of large energy under deformations amounting to several units, when the variation of the adhesion energy as a function of distances between the crystal ions experiences a discontinuity at the maximum value of this energy.

[1] P. Bridgman, Investigations of Large Plastic Deformations and Explosions, (Russ. Transl.) IIL, 1955.

[2] G. S. Zhdanov, Fizika tverdogo tela (Solid State Physics), MGU, 1961.

[3] P. Mac-Master, Non-destructive Testing Handbook, N. I., 1959.

[4] F. P. Bowden and A. D. Yoffe, Initiation and Growth of Explosion in Liquids and Solids, Cabridge, 1951.

EPR IN RUBY IN A CONSTANT ELECTRIC FIELD WITHOUT A MAGNETIC FIELD

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The energy levels of ruby Cr^{3+} ions, in the absence of an external magnetic field and with an electric field turned on, are described by a spin Hamiltonian

$$\hat{H} = D[\hat{S}_z^2 - \frac{1}{3}s(s+1)] + \sum_i \sum_{j \leqslant k} \frac{1}{2} R_{ijk} E_i (s_j s_k + s_k s_j), \tag{1}$$

where $s = 3/2$, $D = -5746$ MHz [2], and R is a tensor having the five independent components R_{111}, R_{222}, R_{333}, R_{123}, and R_{113}. The coordinate axes are those used in [1]. In particular, the z axis coincides with the crystal c axis.

It is seen from (1) that the frequency ν of the transition between two Kramers doublets depends in general on the magnitude and direction of the external electric field E. Regarding the second term in (1) as a perturbation of the first, we obtain, accurate to first order in perturbation theory,

$$\nu = 2|D| \pm 3|R_{333}| E_z. \tag{2}$$

The two signs in (2) correspond to the two non-equivalent positions of the Cr^{3+} ion, which are related by the inversion transformation. Figure (a) shows the energy levels of the Cr^{3+} ion vs. the field E. The dependence of the level positions on the electric field makes it possible to observe the EPR line in a zero external magnetic field by sweeping the external electric field.

The experiment aimed at observing such a line was carried out with a direct-amplification EPR spectrometer with a klystron operating in the 11 - 12 GHz range. To increase the sensitivity, the electric field was modulated at 680 Hz frequency (the modulation amplitude could be varied). The signal was amplified with a narrow band amplifier and recorded with an automatic plotter after synchronous detection at the modulation frequency.