conduction. The solutions of these continuum equations for various "steep-gradient" problems can then also be compared with the corresponding exact microscopic solutions. This provides some insight into the range of validity of the Navier-Stokes equations for gases.

Extensive calculations are now in progress on several such problems, e.g., shear flow, heat transfer between parallel plates, structure of shock fronts, atmosphere-meteor interaction problems, etc. A more detailed account of the work, together with the results of the calculations, will be published in due course.

* The research reported in this paper has been supported by the Geophysics Research Directorate, Air Force Cambridge Research Center, under a contract with Harvard University.

[1] Bhatnagar, Gross, and Krook, Phys. Rev. **94**, 511 (1954).
[2] E. P. Gross and M. Krook (to be published).
[3] V. Kourganoff, *Basic Methods in Transfer Problems* (Oxford University Press, Oxford, 1952).
[4] H. M. Mott-Smith, Phys. Rev. **82**, 885 (1951).
[5] C. S. Wang Chang and G. Uhlenbeck, University of Michigan Engineering Research Institute Report, Project M999, September, 1953 (unpublished).

Photoluminescent Modulation in Nonuniformly Excited ZnS Phosphors

R. E. HALSTED
General Electric Research Laboratory, Schenectady, New York
(Received July 18, 1955)

PHOTOLUMINESCENT modulation, which is described below, provides a simple demonstration of *n*-type photoconductivity in some ZnS phosphor powders and clarifies the role of conduction electrons in the luminescent process.

Irradiation of a phosphor at wavelengths shorter than the fundamental absorption edge creates free electrons and holes which recombine preferentially at luminescent centers. Strong absorption confines this ionization to a small region near the irradiated surface. An alternating electric field applied parallel to the incident radiation moves mobile charge carriers in and out of this region. If electrons provide the dominant charge transport, luminescent recombination proceeds at a rate dependent on the electron density in the region of initial ionization. Maximum recombination rate occurs when the electrode on the irradiated side of the sample is becoming positive for a phosphor specimen so mounted between electrodes that no charge is introduced through its surface. If holes provide the dominant charge transport, recombination will be favored when the electrode on the irradiated side is becoming negative.

If luminescent recombination is proportional to the instantaneous density of the mobile carrier in the ionization region, pronounced photoluminescent modulation should occur. One would anticipate a limited variability in the phase and complexity in wave form of such modulation from its dependence on the details of charge motion. Nevertheless, the sign of the mobile carrier is unambiguously identified by the phase of photoluminescent modulation observed.

Such modulation has been observed with 2537 A excitation of ZnS:Ag, Cl and ZnS:Cu, Al; and 3650 A excitation of ZnCdS(35, 50, and 85% Cd):Ag, Cl and ZnSSe(20% Se):Cu, Cl phosphor powder samples. These were prepared by dispersing the phosphor in an organic film between plane electrodes—one transparent. The ultraviolet lamps were dc operated. The photoluminescence was observed with a photomultiplier and displayed on an oscilloscope. Filters were used to confine excitation and observation to the desired wavelengths.

Photoluminescent modulation with a fundamental frequency component equal to that of the applied sinusoidal voltage was observed in each case. The luminescent maxima occurred when the irradiated side of the samples was becoming positive or at its positive maximum. Detectable modulation occurred at average sinusoidal field strengths as low as 10 volts/cm. Irradiation at a wavelength longer than the absorption edge or application of the electric field perpendicular to the incident radiation produced the previously reported modulation with a fundamental frequency component twice that of the applied field and a higher voltage threshold for detection.[1] The observations were not complicated by changes in the average photoluminescent emission at field strengths below 10^3 volts/cm. At 10^3 volts/cm modulation amplitudes greater than 50%[2] were observed in some samples. Further examination of the 3650 A excited samples revealed a slow decrease of modulation amplitude with increasing excitation intensities between 0.1 and 10 microwatts/cm^2. The modulation amplitude increased slowly with increasing frequency from 20 to 20 000 cycles/sec.

The observations require electrons associated with the luminescent process to travel distances greater than activator separation. Luminescent emission must be strongly dependent upon the instantaneous free electron density in the excitation region. The weak frequency dependence suggests a ratio of electron to hole drift mobilities greater than 1000.

These observations appear incompatible with a recently proposed model for sulfide phosphors requiring emission by hole capture,[3] and limit possible separation of luminescent and volume photoconductive processes in these materials.[4,5]

The author gratefully acknowledges the helpful suggestions and criticisms of S. Roberts and F. E. Williams, and the assistance of H. S. Dunkerley with a portion of the experimental work.

[1] F. Matossi, Phys. Rev. **94**, 1151 (1954).
[2] Percent photoluminescent modulation = 100(maximum − minimum)/(maximum + minimum).
[3] J. Lambe and C. C. Klick, Phys. Rev. **98**, 909 (1955).
[4] R. H. Bube, Phys. Rev. **83**, 393 (1951).
[5] H. Kallman and B. Kramer, Phys. Rev. **87**, 91 (1952).