EMISSION SPECTRUM OF A DETONATION WAVE IN NITROMETHANE

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Emission spectra were obtained for a detonation front in nitromethane over the range 3800-8000 A on a medium-dispersion spectrograph. The spectra were found to be continuous without any lines or molecular bands.

Preliminary measurements showed that the energy distribution in the spectrum differs from a Planck distribution.

It should be recalled that the first experiment in which an emission spectrum of explosion products was obtained successfully was that of M. L. Alentsev, A. F. Belyaev, N. N. Sobolev, and B. M. Stepanov [1]. In this experiment, the spectra were obtained from the explosion of liquid nitroethers on a spectrograph with small dispersion, and the color temperature was calculated. In order to eliminate luminosity from the shock wave in air, which originates as a result of the dispersal of the combustion products, a water jacket was used, but its action was difficult to control, because of the absence, at that time, of suitable equipment.

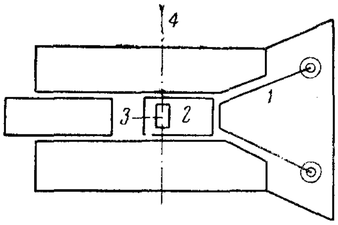

Fig. 1.

Later, in experiments carried out by V. A. Dement'yev and V. N. Kologrivov [2], at the suggestion of M. A. Sadovskii an attempt was made to obtain the emission spectrum for the explosion of a solid explosive in vacuo. The spectra were recorded by means of an ISP-51 spectrograph with a short-focus (120 mm) camera. The vacuum (5-10 mm Hg) was used to exclude luminosity from the shock wave in air. Since the illumination time on emergence of the detonation at the surface was of order 1 μsec, the spectra obtained were very weak and, in addition to the continuous background, they contained a number of molecular bands, the majority of which may be related to luminosity due to the shock wave in the rarefied air.

The color temperature was calculated from the spectra obtained. After the appearance of photomultipliers, a photoelectric procedure was also used for determining the detonation temperature; this had a high sensitivity and a large time resolution. Thus, in Gibsen's [3] and I. M. Voskoboinikov's [4] experiments the detonation luminosity was recorded by means of photoelectric devices with several channels covering different spectral regions of the order of several hundreds of angstroms in width. The color temperature was calculated from the measured ratio of the total intensities in these spectral regions on the assumption that the illuminated object is a gray body. Despite the refinements mentioned, this procedure did not permit the total energy distribution in the spectrum to be observed.

The present paper is devoted to the emission spectrum from the detonation front in nitromethane (NM). In order to obtain the spectra, a spectrograph of medium resolving power was used (ISP-51 with a camera of focal length 27 mm). The spectra were recorded on aerophoto film (Isopanchrom Type 13).

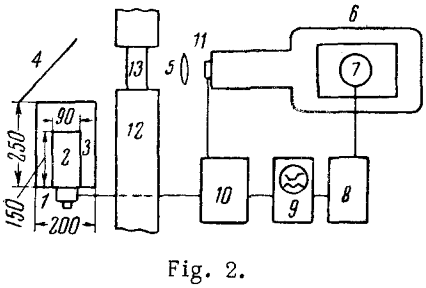

Fig. 2.

The luminosity was observed from the end face, since side observation is complicated by the presence of perturbation waves. In order to eliminate shock wave luminosity in the air, we used a water jacket, whose action is based on the fact that after shock heating the water ceases to transmit light and also hinders the dispersal of the explosion products.

Preliminary experiments showed that the water jacket does not completely exclude extraneous illumination. If the jacket is sufficiently massive, it will safely screen the light from the explosion products over a relatively long time. However, even a massive jacket is shattered so much that the shock wave which forms ahead of it causes air luminosity, as a result of which a continuous spectrum is recorded on the film with superimposed individual lines and bands. It should be emphasized that the simultaneous recording of this process by a spectrophotometric recorder does not permit this illumination to be observed, since the sweep rate of the SPR is too high. In order to eliminate the light, a high-speed shutter was constructed (Fig. 1), the action of which is based on the rapid expansion of a nichrome wire 1 as a result of discharging into it a condenser bank with a capacity of 25 μF charged to 2 kV. Synchronization with the process involves closure by the explosion of the charged line contacts. As a result of closure of the contacts a short but intense current pulse is applied to the nichrome wire; this heats it up and causes it to expand rapidly. The wire pushes the carriage 2 from the channel 3, which has a width of 2 mm, and this closes the spectrograph slit 4 (0.4 mm). The shutter was calibrated by means of a photoelectric device at the exit from the spectrograph. The closure time of the shutter was found to be 120-140 μsec.

The use of the shutter in control experiments showed that the continuous and line spectra originating as a result of dispersal of the explosion products were completely eliminated. After this, tests were run to obtain the emission spectrum of a detonation wave front in nitromethane by means of the combined use of water jacket and shutter. The layout of the equipment is shown diagrammatically in Fig. 2. Here, 1 is the active charge; 2 — the nitromethane container; 3 — water; 4 — mirror; 5 — lens; 6 — spectrograph; 7 — photomultiplier; 8 — amplifier; 9 — oscillograph; 10 — shutter control panel; 11 — shutter; 12 — shielding wall; 13 — illuminator. The image of the nitromethane container 2, obtained by means of the mirror 4 and the lens 5 with a focal length of 90 mm at the spectrograph slit, was 2 mm. At the same time, the shutter diaphragm 11 was 5 mm high. This was necessary in order to control the illumination outside the nitromethane container. The height of the nitromethane container varied from 100 to 200 mm, and the illumination time of the detonation front from 16 to 32 μsec.

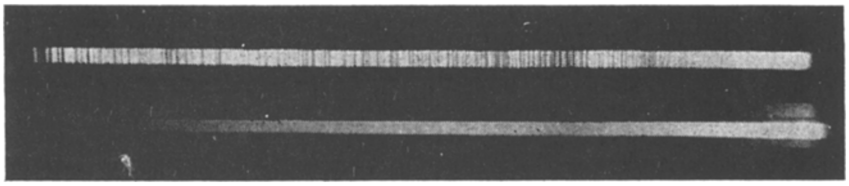

Fig. 3.

In order to reduce the time from the beginning of detonation of the nitromethane to closure of the shutter, initiation of the nitromethane was delayed by 70 μsec relative to the instant of triggering of the shutter mechanism by means of the detonating cord.

As a result of these experiments several emission spectra were obtained and analyzed in the range from 3800-8000 Å. A typical spectrogram, together with the iron reference spectrum, is shown in Fig. 3. The spectra were found to be continuous and had good optical density. By means of calibrated sections of the shutter diaphragm it could be confirmed that the constant illumination from the active charge and illumination by the explosion products through the shock-compressed water gave an insignificant background in the long-wave region of the spectrum.

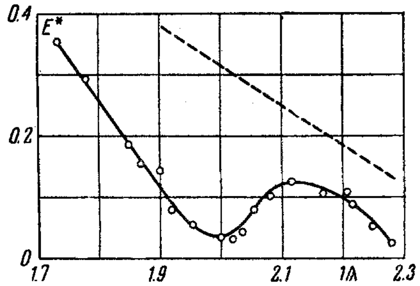

Fig. 4.

The energy distribution in the spectra was measured by the normal procedure of heterochromatic photometry described in [5].

A tungsten ribbon-filament lamp was used as a standard source with an exposure time of 10^{-2} to 10^{-3} sec. A typical spectrogram in the region of 4200-6400 Å is shown in Fig. 4, in which which

$$E^* = \log(E_1 / E_2) + \text{const.}$$

Here E_1 and E_2 are the monochromatic luminances of the standards and of the nitromethane, and $1/\lambda$ is a quantity, the reciprocal of the wavelength expressed in μ.

The dashed line corresponds to the relative intensity distribution in a black body spectrum with a temperature of 3800°K (the color temperature of the standard lamp was 2700 ± 100°K). It can be seen from Fig. 4 that the energy distribution in the emission spectrum of the detonation wave from the end of a charge in nitromethane is not a Planck distribution. This result, however, is not unexpected. Obviously, it is governed by the specific nature of the radiation source, that is, the detonation wave. Let us consider this problem in more detail.

In order to define more precisely the equation of state of the detonation products, it is necessary to determine experimentally the temperature T, of these detonation products (DP) in the Chapman-Jouget plane, i. e., in the region where chemical reaction has practically finished. Determination of the detonation temperature was found to be possible only on the basis of a simplified optical procedure, which is normally applicable to emitters whose spectra are continuous over the wavelength range investigated. In order to determine the temperature by this procedure it is necessary to obtain the spectral energy distribution in the radiation and, in addition to this, to determine by an independent method the dependence of the absorption coefficient of the irradiated object on the wavelength. The simultaneous use of both these data enable us to confirm that the radiation is thermal and to determine the true temperature. It should be added that this is only adequate for determining the temperature of bodies which are uniform in temperature.

The application of this method to the variation of T encounters certain difficulties. According to what has been stated above, in order to determine T it is necessary to obtain the emission spectra of the detonation products in the Chapman-Jouget plane and to determine in them the spectral distribution of the absorption capability. Since chemical reaction in the Chapman-Jouget plane has practically finished and the temperature gradient is relatively small, the condition of temperature uniformity is fulfilled for the detonation products. The absence of significant temperature gradients and the large value of the density permits the assumption to be made that for every wavelength the optical layer is thick and that consequently the energy distribution in the spectrum of the detonation products should correspond to that of a black body.

Unfortunately, it is not possible to obtain the spectrum of the detonation products in the Chapman-Jouget plane directly, for example, from the side of the propagating wave, since all transparent substances do not transmit light after intense shock heating. Consequently, it is necessary to observe the illumination from the detonation wave only from the end of the charge, as a result of which the luminance of essentially all the reaction zone is recorded. The presence in the zone of a fast chemical reaction does not exclude the probability of nonthermal radiation from individual regions of the zone. Moreover, the products formed from partially completed reactions may absorb selectively the radiation of the detonation products from the Chapman-Jouget plane and thereby distort the distribution of their spectral energy.

It has been established [6] that shock-compressed nitromethane, even in the absence of a chemical reaction, strongly absorbs light, but the mechanism and spectral dependence of this absorption are at present unknown.

Thus, even in regions of the zone where reaction has not yet been initiated, distortion of the radiation spectrum from the Chapman-Jouget plane is also possible. If, moreover, it is assumed that there is no selective absorption in the zone, the presence of temperature gradients should lead to the appearance of self-reversal, which will also distort this spectrum and lead to an underestimate of the color temperature [7].

The presence of a detonation with a multifront appearance, established in [6, 8], still further complicates the problem of determining the temperature of the detonation products in the Chapman-Jouget plane. We note that in principle the possibility is not excluded that for certain explosives the superposition of radiation and absorption of the different regions may lead to the spectrum obtained having a Planck energy distribution within the limits of experimental accuracy, but in the light of the above discussion it is difficult to calculate the temperature in the Chapman-Jouget plane from this spectrum.

Thus, the accuracy of the temperature determination carried out in the corresponding experiments obviously indicates the repeatability of the experiments rather than the accuracy of the determination of the true temperature of the detonation products in the Chapman-Jouget plane.

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