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STUDY OF RADIATION SPECTRUM OF GASES HEATED BY STRONG SHOCK WAVES

A. A. KON'KOV and V. P. IONOV
The Krzhizhanovsky Power Institute, Moscow, U.S.S.R.

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Аннотация—В условиях ударной трубы за бегущей и отраженной ударными волнами исследован спектральный состав излучения азота, кислорода, окиси и двуокиси углерода и их смесей в диапазоне температур 4000°–8000°К и давлений 10–100 атм.

INTRODUCTION

FOR the problems of heat transfer at high temperatures it is necessary to account for the radiant contribution. The latter cannot be always predicted since for some gases the power of oscillators is not known exactly [1]. The radiating capacity of a gas should therefore be studied experimentally, and first of all it is necessary to preliminarily find out the contribution of which components and which spectrum region will be determinant. For this purpose an investigation was carried out of the radiation spectra of the following gases and their mixtures heated by strong shock waves: nitrogen, oxygen, carbon monoxide and dioxide.

DESIGN OF A SHOCK TUBE AND METHODS FOR MEASURING SHOCK WAVE VELOCITY

A shock tube is comprised of high- and low-pressure sections separated by a diaphragm made either of copper or of stainless steel (Fig. 1).

The high-pressure section represents a steel cylinder of about 150 cm in length, 3 cm i.d. and 6 cm o.d. With the help of a fore pump of the PBH-20 type and a pipe-line system the section was first pumped out to the pressure of 10^{-2} mmHg and then filled with hydrogen, helium, oxygen or with a mixture of these gases. Two electrodes which produce a discharge for inflamation of gas mixtures are built in a butt end of the section.

The gas mixture consists of hydrogen (8·5 per cent), oxygen (17 per cent) and helium (74·5 per cent). The initial pressure in the section is 25–35 atm and is controlled by a standard pressure gauge.

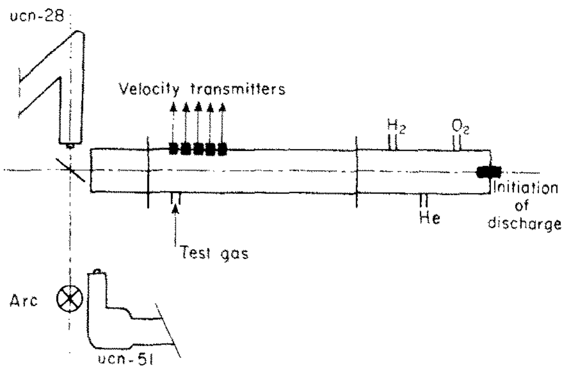

FIG. 1. Schematic drawing of a shock tube.

The low-pressure section consists of two steel cylinders with inspection windows. The total length of the section is 350 cm, the i.d. is 3 cm and the o.d. is 6 cm. The section is preliminarily pumped out to the pressure 10^{-2} mmHg (by a pump of the PBH-20 type) and then is filled with a working gas. Pressure is controlled by standard and oil vacuum gauges and is 6·5 mmHg.

The initial surfaces of the high- and low-pressure sections were chrome-plated. Before a test run the internal channel of the apparatus was thoroughly rubbed by flannel wetted in rectified alcohol in order to decrease the effect of admixtures. After the run the inspection windows were processed with acid.

The velocity of an incident shock wave was measured by means of ionization gauges. Signals were recorded on an oscillograph of the ИО-4 type. For various gases and mixtures, velocities ranged from 2–3 km/s to 6–7 km/s and for nitrogen, up to 10 km/s; the accuracy of measurement was ± 7 per cent. Temperature and pressure behind incident and reflected shock waves were calculated by the velocity of an incident shock wave under the assumption of thermodynamic equilibrium and the fulfilment of conservation laws.

RADIATION SPECTRA OF GASES HEATED BY STRONG SHOCK WAVES

Radiation spectra were investigated in visible and ultra-violet regions. A quartz spectrograph ИСП-28 was placed opposite to a butt end window thus (Fig. 1) that radiation from incident and reflected shock waves was fixed on a film as not resolved in time.

The evaluation showed that radiation of a gas, being behind a reflected wave, as compared with radiation of a gas being behind an incident shock wave, makes a determinant contribution. Spectra were fixed on a film of type "Д" or "Panchrom X". The corresponding spectra of air ($T = 5100°K$, $P = 10$ atm) and of nitrogen ($T = 9800°K$, $P = 100$ atm) are given in Fig. 2 and Fig. 3 as typical spectra.

The consideration of spectra shows that they are characterized by the presence of a continuous spectrum, admixture lines of sodium, calcium, iron, copper and bands of calcium oxide and by the absence of oxygen and nitrogen bands.

The following bands of the violet system CN are found in the air spectrum: 4216·0; 4197·2; 4181·0; 4167·8; 3883·4; 3871·4; 3861·4; 3854·7 Å (Fig. 2).

A similar fact is established by the authors of work [2] when investigating radiation spectra of the air heated by a shock wave. Some bands in the air spectrum are presumably identified with molecule bands of NO_2.

With increase in temperature and pressure behind a reflected shock wave (at velocities of an incident wave 5–6 km/s and higher) the continuous radiation begins to play its essential role, and there appear reversed lines of sodium, calcium and copper on its background (Fig. 3). Reversed lines of admixtures show the presence of temperature gradients in a heated gas.

In addition, spectra of CO_2 and of mixtures of CO_2 and N_2 are considered. Fig. 4 presents a radiation spectrum of a mixture (CO_2 is 25 per cent and N_2 is 75 per cent) at $T = 9000°K$, $P = 50$ atm.

The absence of bands of N_2 and CO_2 and the presence of a continuous spectrum, admixture lines and the violet system of CN are characteristic of this spectrum.

The most intense bands are in the first of the above mixtures. The violet system of CN in the spectra of the above mixtures is more intense as compared with the bands of CN in the radiation spectrum of an air. For example, the band $\lambda = 4578$ Å in the radiation spectrum of the air is seen weakly and may be identified only presumably whereas in mixture spectra it is seen quite distinctly.

Moreover, some bands which are presumably identified with bands of NO_2 are observed in the given mixtures.

When the velocity of a travelling detonation wave is 7 km/s the gas radiation spectrum behind a reflected shock wave was also obtained by gas mixtures: 50 per cent of CO and 50 per cent of O_2 (gas parameters were not calculated) (Fig. 5).

About 100 bands belonging to the Fox–Daffendak–Barker system of a molecule of CO_2 are found and about ten bands are identified with radiation bands of the radical OH. In addition, the continuous radiation, admixture lines of iron, sodium, calcium, copper and bands of calcium oxide are revealed in the spectrum of the given mixture as well as in the above spectra.

INTERPRETATION OF RESULTS

As was mentioned above, the presence of the continuous radiation and of admixture lines (iron, copper, sodium, calcium, calcium oxide, chrome) is general for the investigated gases and mixtures in their radiation spectra. From the experiments conducted it follows that increase in both pressure and temperature leads to a considerable increase in the continuous-radiation

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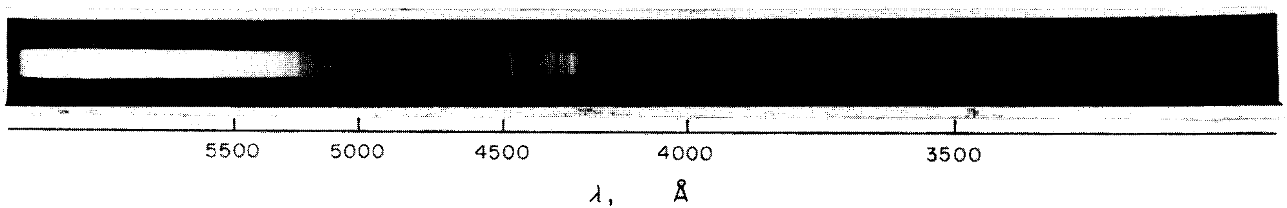

Fig. 2. Radiation spectrum of air heated by shock wave.

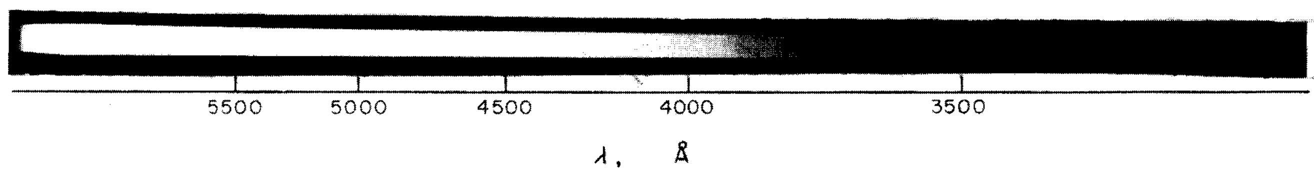

Fig. 3. Radiation spectrum of nitrogen heated by shock wave.

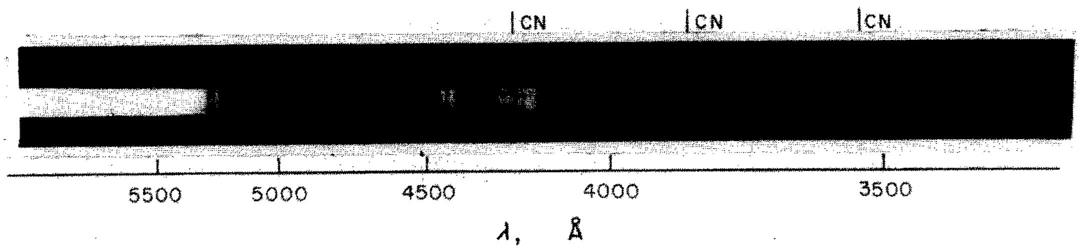

FIG. 4. Radiation spectrum of the mixture of CO_2 (25 per cent) and N_2 (75 per cent) heated by shock wave.

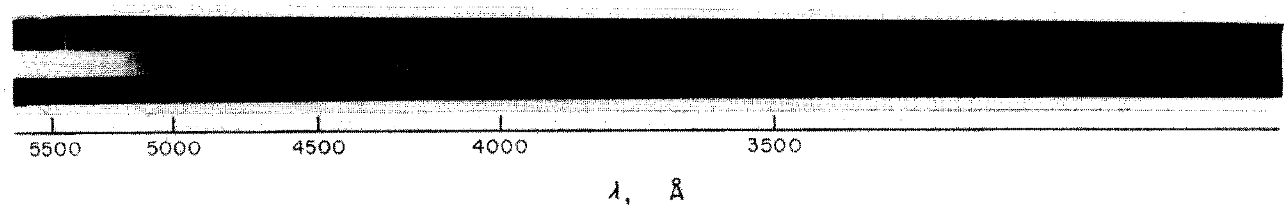

FIG. 5. Radiation spectrum of the mixture of CO (50 per cent) and O_2 (50 per cent) behind a reflected detonation wave.

intensity. If admixture lines give apparently relatively small contribution to a radiant flow, the continuous radiation may influence greatly.

Some assumptions on the reasons of its origin may be suggested. First of all it should be noted that free-free and free-bound electron transitions, appearing as a result of ionization of the gas investigated, lead to the continuous radiation. In addition, the gas contains admixtures as well as metallic and non-metallic particles that leads to the additional rise of the continuous radiation.

While investigating all the above gases and mixtures nitrogen and oxygen bands were not found. This may be conditioned by the fact that they are shielded by a continuous background and by admixture lines.

From the viewpoint of radiative heat transfer CN gives an essential contribution in carbon–nitrogen mixtures and in the air over the temperature range from 5000° to 10 000°K and pressure range from 10 to 50 atm in blue and neighbouring spectrum parts. For a mixture of CO_2 (25 per cent) and N_2 (75 per cent) the band intensity of CN is higher than in a mixture where CO_2 is 75 per cent and N_2 is 25 per cent that agrees with the concentration of CN in these mixtures. The appearance of the bands of CN in an air radiation spectrum is caused by the fact that a carbon dioxide gas is present as an admixture in the air [2].

About 100 of carbon-dioxide-gas bands of the Fox–Daffendak–Barker system are found in a carbon–oxygen mixture behind a reflected detonation wave (velocity of an incident wave is 7 km/s) in an ultra-violet spectrum-region. Bands of the radical OH are also observed that are apparently connected with the in evitable penetration of water vapour into the mixture investigated. An analogous result is established in work [3] where the continuous radiation and linear structure are also found when investigating the gas radiation behind a detonation wave. The author identified some bands with those of the radical OH, and the remainder, as in the present case, may not be related to a flame spectrum of CO.

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Abstract—The spectral composition of radiation of nitrogen, oxygen, carbon monoxide and dioxide and of their mixtures is investigated over the temperature range from 4000° to 8000°K and pressure range from 10 to 100 atm under the conditions of a shock tube behind travelling and reflected shock waves.

Résumé—Le spectre du rayonnent de l'azote, de l'oxygène, de CO et CO^2 et de leurs mélanges est étudié entre 4000° et 8000°K pour un domaine de pression allant de 10 à 100 atmosphères, dans les conditions rencontrées dans un tube de choc derrière les ondes de choc mobiles et réfléchies.

Zusammenfassung—Die spektrale Zusammensetzung bei der Strahlung von Stickstoff, Sauerstoff, Kohlenmonoxyd und Kohlendioxyd und deren Gemischen wurde im Temperaturbereich 4000 bis 8000°K und im Druckbereich von 10 bis 100 atm hinter einer fortschreitenden und reflektierten Stosswelle im Stosswellenrohr untersucht.