Soviet-era science, translated into English

SHORT-WAVE RADIO EMISSION AND THE SHOCK WAVE OF AN EXPLOSION

Physics

1970

SovietRxiv

View the original and related papers at https://sovietrxiv.org/items/ru-197001.48988

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

Abstract

Full Text

UDC 537.530

Physics

A. P. BORONIN, Yu. A. MEDVEDEV, B. M. STEPANOV

SHORT-WAVE RADIO EMISSION AND THE SHOCK WAVE OF AN EXPLOSION

(Presented by Academician S. A. Khristianovich, 3 VII 1969)

1. Numerous phenomena of both natural origin (thunderstorm discharges, meteors, etc.) and artificial origin (flashes of ionizing radiation, explosive processes, etc.) are accompanied by pulses of an electromagnetic field. At present a number of works have been published in which mechanisms of the transformation of various physical factors into an electromagnetic field have been considered ([1–7]) and others, as well as a number of works devoted to the experimental study of the dependence of the characteristics of the excited field on the parameters of the initial process (see, for example, ([8–12])).

An inverse problem can also be formulated, consisting in determining the parameters of the processes from the recorded characteristics of the pulsed field accompanying them.

In the present paper one such problem is considered: the recording and study of the time characteristics of the short-wave radiation of the explosion of solid high-explosive charges make it possible to estimate, at certain instants of time, the state of gas ionization behind the shock wave, and also to identify the component that makes the principal contribution to the electron density during thermal ionization of the gas.

2. In the experiments carried out, the short-wave field of radio emission,* accompanying the detonation (by the firing method) of spherical charges of the TG 50/50 type, was received by whip antennas 1 m long, located at a distance of 1.5 m from the center of the explosion. The selection and recording of the time dependence of the components of the radio-emission field in various parts of the spectrum were carried out by means of short-wave receivers of the ESM-180, ESM-300 type (passband $\Delta f = 200$ kHz), an R-250M (14 kHz band), and OK-17 oscillographs triggered by the light pulse. The signals were recorded after detection, and also after an intermediate-frequency amplifier (i.f.). The intermediate frequency of the ESM-type receivers was 3 MHz, and that of the R-250M type was 220 kHz. Only the frequency region above 1 MHz was investigated, since

SovietRxiv

Fig. 1

Figure 1: Fig. 1

recording of the field in the region below 1 MHz was sharply hindered because of the increase in the level of interference produced by radio stations. Simultaneously, the time-integrated spectrum of the light emission of the explosion was recorded on an ISP-51 spectrograph.

3. It was found that the amplitude of the radio-emission signal decreases with increasing frequency, so that at frequencies above 100 MHz the signal level does not exceed the sensitivity of the receivers ($\sim 1\ \mu$V). After detection, the signal from the receiver has the form of a sequence of spikes, each of duration $1/\Delta f \sim 5\ \mu$s, arising with random amplitude and phase. It is characteristic that the signal appears after a time t_0 from the moment of explosion, and t_0 depends on the energy of the explosion and on the frequency. The time of appearance of the signal is more clearly expressed on oscillograms recorded from the i.f. amplifier. One of them is shown in Fig. 1. The upper trace is radio emission at a frequency of 90 MHz, the lower at 1.5 MHz. Charge mass 600 g, sweep duration 400 μsec. It is seen that the radiation at the higher frequency appears later than at the lower one.

When charges with masses of 50, 100, 225, and 600 g were exploded, it turned out (see Fig. 2) that at a fixed frequency f the time t_0, within the accuracy of the measurements, satisfies the condition of self-similarity

$$t_0 = t_0^0(f) m_{\text{kg}}^{1/3}, \tag{1}$$

where the dependence $t_0^0(f)$ is weak—approximately logarithmic.

Fig. 1

The main experimental facts observed can be explained if it is assumed that the short-wave radio emission is generated by the products of the explosion and, during the time t_0, is screened by a thermally ionized layer of heated air: the shock wave—the front boundary of the explosion products. In this case the phenomenon should not be strictly self-similar, since, in addition to the gas-dynamic quantities characterizing the explosion, there is also a non-self-similar parameter

---

* The study carried out in (^{10}) of the dependence of the field intensity on distance from the explosion showed that, in the frequency range investigated, it is radio emission that is recorded, and not a quasistatic or induction pickup of the near zone, as studied in (^{11,12}). This circumstance was used below in the interpretation and quantitative processing of the experimental results.

SovietRxiv

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

–the wavelength of the received radio emission. Therefore, although at the time $t_0 = t_0^0(f) m_{\mathrm{kg}}^{1/3}$ the state of the gas in the heated layer is the same, nevertheless the attenuation of a radio wave of a given frequency is different for explosions of different scales owing to differences in the corresponding thicknesses of the heated layer. However, the state of the gas very strongly (exponentially) determines the absorption, whereas the non-self-similar parameter that violates the self-similarity of the phenomenon enters into the pre-exponential factor, which explains the observed self-similar character of dependence (1).

Fig. 2

Since in the present case the collision frequency of the charged particles is higher than the frequencies investigated, then for any mechanism of conductivity (electronic and ionic) the absorption increases with increasing frequency, which explains the observed delay in the time of appearance of the high frequency relative to the low one. The exponential dependence of the degree of ioniza-

···of the state (temperature) of the gas in the layer leads to a logarithmic dependence $t_0(f)$. The mechanism by which radio waves are excited by the explosion products is not investigated in the present article.

4. Such an interpretation of the experimental results permits a simple and sufficiently complete quantitative description.

If it is assumed that the conductivity of the air in the heated layer is due to electrons, whose concentration can be calculated by the Saha formula, then the condition for attenuation by a factor e of the radio waves generated by the explosion products in a heated layer of thickness Δ at the time t_0 can be represented in the form

$$\frac{\sqrt{2\pi f}}{c} \int_0^{\Delta} \left\{ \left[1 + \frac{1.23 \cdot 10^{31} T^{3/2}(r, t_0)}{P(r, t_0) \cdot 2\pi f} \exp\left[-\frac{I}{kT(r, t_0)} \right] \right]^{1/2} - 1 \right\}^{1/2} dr, \quad (2)$$

where $T(r, t_0)$ and $P(r, t_0)$ are the distributions of absolute temperature and pressure in atmospheres along the radius at the time t_0; r is measured from the front boundary of the explosion products; I is the effective ionization potential of the component responsible for the production of electrons; k is Boltzmann' s constant.

SovietRxiv

Fig. 3

If the temperature distribution $T(r, t_0)$ is known, then the criterion for the applicability of relation (2) to the description of the experimental results may be the coincidence of some constant parameter found from (2) for different experiments (different t_0 and f). It is expedient to choose the effective ionization potential I as such a parameter, since relation (2) is very sensitive to changes in the value of I.

Let us check the fulfillment of condition (2) at the moments when the radio emission of an explosion of $m = 225$ g appears at frequencies of 1.5 and 30 MHz. These instants of time correspond to the values of the shock-wave radii $r'' = 10r_0$ and $r'' = 12r_0$ [13] (r_0 is the initial radius of the charge). As far as we know, direct measurements of the pressure distribution behind the shock-wave front have been carried out at the present time [13], but there are no experimental data on the temperature distribution. Therefore the temperature distributions behind the front at the instants of time of interest to us were found from the measured pressure distributions and calculated density distributions [13], with the use of data on the thermodynamic state of air [14] at these temperatures and densities. We note that for what follows, not so much the absolute as the relative temperature distributions behind the shock-wave front are important. The relative temperature distributions found behind the front are shown in Fig. 3 (T'' is the front temperature).

In the most essential region near the boundary of the explosion products, the temperature distribution $T(x)$ can be interpolated in the form

$$T(x) = T' \exp(-\beta x), \qquad 0 \le x \le x_0; \tag{3}$$

$T' = T(0)$ is the relative temperature at the front boundary of the explosion products; x is the distance from the boundary in units of the shock-wave radius r''.

For $r'' = 10r_0$, $T' = 7000$°K, $\beta = 52.5$, $x_0 = 0.027$, $T(x_0) = 2800$°K, $P(0) = 31.5$ atm, $P(x_0) = 34.5$ atm, $T'' = 2000$°K. For $r'' = 12r_0$, $T' \le$

$= 6000$°K, $\beta = 61$, $x_0 = 0.022$, $T(x_0) = 2200$°K, $T'' = 1600$°K, $P(0) = 22$ atm, $P(x_0) = 24$ atm.

In calculating (2), the pressure in the region $x \le x_0$ may be taken as constant and equal to $P(0)$. The left-hand side of relation (2), taking (3) into account, is represented in the form

$$F(A, a) = b \int_1^d \left\{ \left[1 + \frac{a}{y^{3/2}} \exp(-Ay) \right]^{1/2} - 1 \right\}^{1/2} \frac{dy}{y}, \tag{4}$$

Fig. 4

Figure 4: Fig. 4

where $A = I/kT'$, $a = 4.3 \cdot 10^{15} T'^{3/2}$, $b = 2.2 \cdot 10^{-4} m^{1/3} \mathrm{kg}^{1/3}$, $d = 4.2$ for $f = 1.5$ MHz, and $a = 1.5 \cdot 10^{13} T'^{3/2}$, $b = 4.6 \cdot 10^{-3} m^{1/3} \mathrm{kg}^{1/3}$, $d = 3.9$ for $f = 30$ MHz.

The dependence of F on the parameter A (the results of numerical integration) for $m = 225$ g at various values of the pre-exponential factor a for 1.5 and 30 MHz is shown in Fig. 4. Within the same limits the value of A (for $F = 1$) changes for different values of b, corresponding to changes in the explosion energy of charges with $m = (50 \div 600)$ g.

Fig. 4

For $f = 1.5$ MHz we obtain $I/kT' = 8.9$, and for $f = 30$ MHz $I/kT' = 13.9$. If, on the basis of the data given above, we take $T' = 7000$°K for $f = 1.5$ MHz and $T' = 6000$°K for $f = 30$ MHz, then we obtain the value of the ionization potential $I = 5.35$ eV from the data at the frequency 1.5 MHz and $I = 7.2$ eV from the data with $f = 30$ MHz. The difference in the values found for I is apparently explained by the considerable uncertainty of the adopted values of T'. The values obtained for the ionization potential are closest to the ionization potential of sodium ($I = 5.14$ eV). The nearest value of the ionization potential is that of NO, 9.5 eV.

Additional spectrographic investigations of the spectrum of the explosion glow carried out in these experiments showed that, in addition to the continuous spectrum, an intense sodium D-line is present.

If the main source of ionization of the air behind the shock-wave front is a sodium impurity, then the value of the ionization potential in (4) should be taken as $I = 5.14$ eV. Then the values of the temperature at the contact surface of the explosion can be refined: $T' = 6700$°K for $r'' = 10r_0$ and $T' = 4300$°K for $r'' = 12r_0$, instead of 7000 and 6000°K, respectively.

In conclusion, we thank V. A. Poltoratskii for taking the spectrum and E. T. Antoshkina for assistance in carrying out the radio measurements.

Received
3 VII 1969

REFERENCES

1. A. S. Kompaneets, *ZhETF*, **35**, issue 6 (12) (1958).
2. V. Gilinsky, *Phys. Rev.*, **137**, No. 1A, A51 (1965).

3. W. J. Karzas, R. Latter, *J. Geophys. Res.*, **67**, No. 12 (1962).

4. O. I. Leipunskii, *ZhETF*, **38**, 302 (1960).

5. V. V. Ivanov, Yu. A. Medvedev, *Astron. Zh.*, **41**, No. 6, 1118 (1964).

6. V. V. Ivanov, Yu. A. Medvedev, *Geomagnetism and Aeronomy*, **5**, No. 2, 284 (1965).

7. Yu. A. Medvedev, B. M. Stepanov, G. V. Fedorovich, *ZhETF*, **37**, No. 11, 2084 (1967).

8. M. A. Cook, *The Science of High Explosives*, N. Y., 1958.

9. W. H. Anderson, C. L. Long, *J. Appl. Phys.*, **36**, No. 4 (1965).

10. T. Takakura, *Publ. Astr. Soc. Japan*, **7**, 210 (1955).

11. L. M. Gorshunov, G. P. Kononenko, E. I. Sirotinin, *ZhETF*, **53**, issue 3 (9) (1967).

12. A. P. Boronin, V. A. Vel' min et al., *PMTF*, No. 6 (1968).

13. V. V. Adushkin, ibid., No. 5 (1963).

14. N. M. Kuznetsov, *Thermodynamic Functions and Shock Adiabats of Air at High Temperatures*, Moscow, 1965.

Note: Figure translations are in progress. See original paper for figures.

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.