On Existence of Free Electrons at the Detonation of Condensed High Explosives

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Abstract

Presence of free electrons can be detected by the electric conductivity. Recently, a high resolution method was developed allowing one to measure conductivity for a variety of condensed HEs [1-5]. Here we show by the comparison of data that there is now significant concentration of free electrons at the detonation of TNT and RDX, both in the chemical peak and in the Taylor wave.

Electric conductivity at detonation of HE

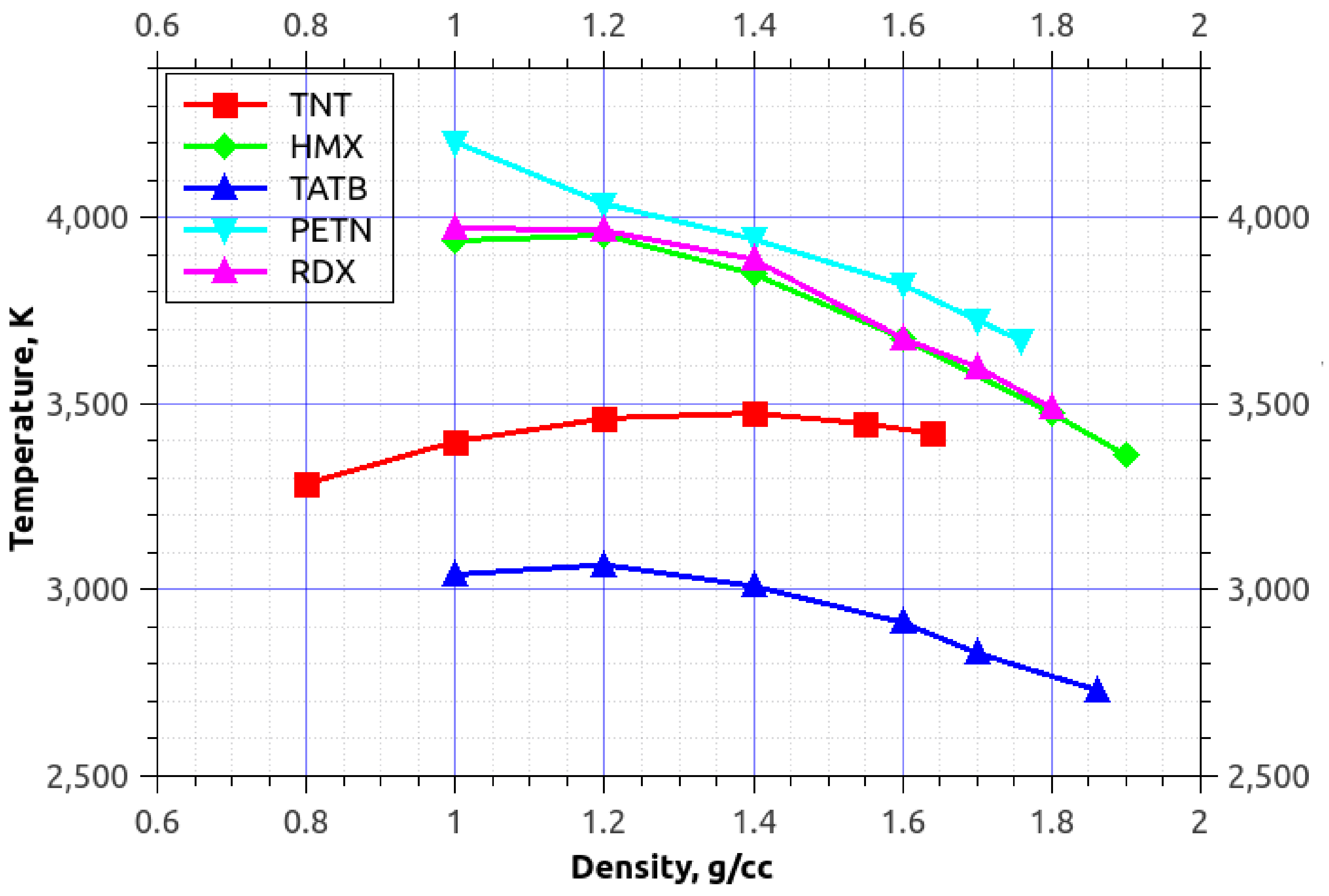
Hypotheses on the nature of the conductivity in the chemical peak (von Neumann peak) and behind the Chapman–Jouguet (CJ) point:
themal ionization, thermoemission, thermal ionization in a dense matter, chemoionization, contact mechanism, ionic mechanism, ionization of water.
Ionic mechanism can be significant at conductivity of ~ 1 Ohm^{-1}cm^{-1}.
Condutivity depends on the carbon content [6,7], the dependence can be approximated as $\sigma(r) = a + \sum\limits_{n=2}^{7} b_n r^n$, where r is the mass fraction of carbon, $a > 0$, $b_n > 0$ are constant coefficients.
Mechanisms of conductivity provided by carbon: chemoionization, thermal ionization, thermoemission, contact mechanism. Except the contact one, all mechanisms need the presence of free electrons.
Chemoionization is the generation of electrically charged particles in chemical reactions. In flames, the conductivity is commonly connected with the following reaction and with the presence of a free electron [8]:

$$CH + O \rightarrow CHO^+ + e^-$$

Chemoionization is connected with the speed of chemical reations which increases when the duration of chemical peak decreases. At the detonation of RDX, PETN and HMX, the conductivity is about 10 Ohm^{-1}cm^{-1}. The speed of chemical reactions in this HEs is much higher than in TNT which has the conductivity of 100 Ohm^{-1}cm^{-1}. Hence, chemoionization is not essential for the conductivity.

The temperature and density in the CJ point

Conductivity at detonation is frequently related to the high temperature. The figure shows the temperature vs density in the CJ point for five HEs $T(\rho)$, $T(\rho)$ calculated using BKW EOS [9].



For HMX, PETN, RDX, fuction $T(\rho)$ is monotonically decreasing with increasing density, small difference at the same density.
For TNT, temperature significantly lower, non-monotonous.
The lowest temperature for TATB, conductivity of ~ 15 Ohm^{-1}cm^{-1} [5] higher than for HMX, PETN, RDX, but lower than for. For all HEs under investigation, maximum coductivity increases with the increase of density. On the contrary, the density dependence of temperarute is non-monotonous. Therefore, the temperature can not be the main cause of high conductivity at detonation of condensed HEs. More detailed analysis and comparison for TNT and RDX.

Influence of high temperatures on the electric conductivity

Themperature is the most uncertain and the hardest for experimental investigattion parameter. Commonly accepted: temperature in TNT is lower than in RDX, PETN, HMX.

Таблица : Temperature and electric conductivity for RDX and TNT

N	HE	ρ g/cm^3	T$_{CJ}$, K	r_{CJ}	σ_{CJ} Ohm^{-1}cm^{-1}	σ_{max} Ohm^{-1}cm^{-1}
1	TNT	1.0	3398	0.128	8.9	15.0
2	TNT	1.6	3434	0.260	26.8	95.2
1	RDX	1.2	3964	0.030	0.4	1.8
2	RDX	1.6	3675	0.066	1.25	4.2

Here, ρ is the density, T$_{CJ}$ is the temperasture at the CJ point calculated using the BKW EOS [9], r_{CJ} is the mass fraction of carbon at this density, σ_{CJ} is the conductivity at the CJ point, and σ_{max} is the maximium conductivity. Даны значения для насыпной плотности и для близкой к максимальной.
Thermoemission and thermal ionization: at high temperatures, free electrons appear. Termoemission is the emission of electrons from caogulated carbon particles. Thermal ionization is the ionization of atoms at high temperature. In both processes, the conductivity increases exponentially with temperature $\sigma \sim \exp(-E/kT)$. Pre-exponential factor which depends on the process is not significant, the behaviour is mainly defined by the exponential. There should be sharp increase of conductivity with the increase of temperature which is not observed. For TNT, the conductivity depends on the density, e.g., on the carbon content, at almost constant temperature. For RDX, the conductivity is essentially lower at significantly higher temperatures. The data given in the Table points to the absence of a significant amount of free electrons.
Ershov [10] made the estimates of the concentration of free electrons at the detonation assuming that the conductivity is due to high temperature. The estimate of the lower limit of the free electron concentration which can be observed: $n_e \sim 10^{20}$ cm^{-3} for TNT, $n_e \sim 10^{19}$ cm^{-3} for RDX and PETN.
Conclusions:
We observed the increasing condutivity in the detonation wave at the decreasing temperature. Such dependence is the evidence of the absence of a significant amount of free electrons at the detonation.

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