Two-temperature heat transfer in a metal and a longitudinal elastic wave generation

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Abstract:

The new version of the classic Danilowskaya's problem is considered. To describe the formation of a longitudinal elastic wave in the metal by a laser beam, we use a two-temperature theory of heating such a metal. There are two temperatures simultaneously, the temperature of the electron gas T_e and the temperature of the ionic lattice T_l, and both are functions of position and time. The energy transferred by electrons to the lattice per unit volume of the crystal per unit time is proportional to the difference $T_e - T_l$. The process is described by three equations

$$\begin{aligned} c_e(T_e)\frac{\partial T_e}{\partial t} &= \lambda \frac{\partial^2 T_e}{\partial x^2} - \alpha \, (T_e - T_l) + r(\boldsymbol{x}, t) \\ c_l(T_l)\frac{\partial T_l}{\partial t} &= \alpha \, (T_e - T_l) \\ \frac{\partial^2 u}{\partial t^2} &= c^2 \frac{\partial^2 u}{\partial x^2} - \frac{\gamma}{\rho}\frac{\partial T_l}{\partial x} \end{aligned} \tag{1}$$

where λ is the lattice heat conductivity coefficient and α is a heat exchange coefficient, c denotes the velocity of the elastic longitudinal wave and ρ stands for the density of the solid. The quantity $\gamma = K\alpha^{\mathrm{E}}$, where K is the modulus of the solid compression and α^{E} is the thermal expansion coefficient.

We give the equations of energy conservation and entropy production, whose thermodynamic consistency is verified. The equations of the problem are quasi-linear, since the specific heat of the electron gas in the considered temperature range depends on the temperature (degenerate electron gas). The one-dimensional process of transmitting thermal energy to the crystal lattice and the formation of mechanical wave is analyzed by the numerical method and illustrated in the pictures for various exemplary cases.

Keywords: degenerate electron gas, relaxation, heat transfer coefficient, energy balance, entropy growth