Equations (3) and (4) were solved by numerical methods with a computer. We used in the calculations $E_n = 3$ kV/cm, $n_0 = 10^{15}$ cm^{-3}, $\mu_2 \sim 100$ cm^2/V-sec, $\mu_1 \sim 3000$ cm^2/V-sec, $E_0 = 10$ kV/cm, and $E_1 = 7.1$ kV/cm for one case and $E_0 = 5$ kV/cm and $E_1 = 2.1$ kV/cm for another case. The results were used to plot G_1/G_0 against f (Fig. b), where G_1 is the conductivity of the sample for an appropriate bias and amplitude of the acting voltage, and G_0 is the active sample conductivity in a weak field.

The calculation results show that a two-valley semiconductor having no negative section in the V(E) characteristic has a negative differential conductivity in a frequency band (Fig. b). With increasing dc electric field intensity, the frequency band in which the negative differential conductivity is observed broadens. The negative differential conductivity of such a semiconductor can be used for generation and amplification. According to the calculations, the efficiency of a generator based on the negative differential conductivity of such a semiconductor is 0.6 - 0.7%.

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THERMOKINETIC EFFECTS IN LIQUID METALS

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Perturbation of the electron subsystem of a metal by a temperature gradient leads to the appearance of forces acting on the ionic "core": 1) the electron "wind" force $F_{ni}^{(0)}$ due to momentum transfer from the electrons to the ions, 2) the direct force $F_q^{(0)}$ exerted on the lattice ions by the thermoelectric field, and 3) the force F_p due to the electron-gas pressure gradient. In a homogeneous unbounded metal, the total density of these forces is equal to zero [1].

Near the metal surface, however, the local mechanical equilibrium may be disturbed. If the electrons are diffusely scattered when they collide with the surface, then a fraction of the momentum flux is transferred to the metal surface and the electron "wind" force at a point z near the metal surface will differ from the volume value, $F_{ni}(z) \neq F_{ni}^{(0)}$. The additional scattering mechanism may change the thermoelectric field E and the force $F_q = qNE$ it exerts on the ionic "core" (q is the ion charge and N the number of ions per cm^3). Thus, the electron kinetic force produced at the surface of the metal in a layer of thickness on the order of the electron mean free path ℓ is

$$F = (F_{ni} - F_{ni}^{(0)}) - (E - E^{(0)})qN. \tag{1}$$

These forces produce in liquid metals thermokinetic phenomena governed by a purely electronic mechanism, namely thermoosmosis (flow of metal) and thermophoresis (motion of particles in the metal). We consider electronic thermoosmosis in a liquid metal. Let the metal be located in a flat capillary (see the figure) of width $a \gg \ell$. The temperature gradient is directed along the x axis ($\nabla T = (\partial T/\partial x)$). The metal circuit is open and the current is equal to zero. In the free-electron approximation the force of the electron "wind" is equal to [1]

$$F_{ni}^{(a)} = \frac{2}{h^3}\int P_a v\sigma(v) f_1 d^3p \qquad (a = x, y, z), \tag{2}$$

where p and v are the momentum and velocity of the electrons, σ(v) is the total cross section for electron scattering in the lattice, and f_1 is the nonequilibrium increment of the distribution function.

The function f_1 is determined by the solution of the kinetic equation

$$-\frac{f_1}{\tau(\epsilon)} = v_z\frac{\partial f_1}{\partial z} + \frac{\partial f_0}{\partial\epsilon}v_x eE + \frac{\partial f_0}{\partial\epsilon}v_x\left\{-\frac{\epsilon}{T} + \left(\frac{\mu}{T} - \frac{\partial\mu}{\partial T}\right)\right\}\frac{\partial T}{\partial x}, \tag{3}$$

where τ(ε) is the relaxation time of the electrons of energy ε and μ is the chemical potential.

The boundary conditions are determined by the character of the electron scattering from the metal surface. We shall assume below that this scattering is completely diffuse.

We can write f_1 in the form $f_1 = f_1^{(0)}\psi(z/\ell\cos\theta)$, where $f_1^{(0)}$ is the nonequilibrium part of the distribution function in the volume of an unbounded metal, and the function $\psi(z/\ell\cos\theta)$ is given by [2, 3]

$$\psi\left(\frac{z}{\ell\cos\theta}\right) = \begin{cases} 1 - \exp\left(-\dfrac{z}{\ell\cos\theta}\right) & \cos\theta > 0. \\ 1 - \exp\left(\dfrac{d - z}{\ell\cos\theta}\right) & \cos\theta < 0 \end{cases} \tag{4}$$

Using the explicit form of the function f_1, we can write F_{ni} in the form

$$F_{ni} = -\frac{8\pi m^3}{3h^3}\int_0^\infty\left\{eE + \left[-\frac{\epsilon}{T} + \left(\frac{\mu}{T} - \frac{\partial\mu}{\partial T}\right)\right]\frac{\partial T}{\partial x}\right\}v^3\sigma\,\ell\phi\left(\frac{z}{\ell}\right)\frac{\partial f_0}{\partial\epsilon}d\epsilon, \tag{5}$$

where

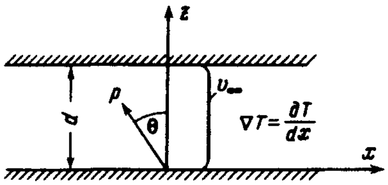
$$\phi\left(\frac{z}{\ell}\right) = \frac{3}{4}\int_{-1}^{+1}\psi\left(\frac{z}{\ell x}\right)\left(1 - x^2\right)dx \tag{6}$$

F_{ni} differs from $F_{ni}^{(0)}$ in that ℓ is replaced by $\ell\phi(z/\ell)$.

The electron "wind" force is determined essentially by the character of the dependence of the electron mean free path on the velocity, $\ell = \ell(v)$, and depends in particular on $d\ell/dv$. To simplify the calculation we consider the case ℓ = const, $d\ell/dv = 0$, and then $F_{ni} = F_{ni}^{(0)}\phi(z/\ell)$. According to [1]

$$F_{ni}^{(0)} = -\frac{\pi^2}{6}\frac{k^2}{\mu}nT\frac{\partial T}{\partial x}, \tag{7}$$

where n is the conduction-electron density. The thermoelectric field at ℓ = const does not vary on the surface, i.e., $E = E^{(0)}$. We thus get for the thermokinetic force



Velocity distribution in a liquid in the case of thermoosmosis in a flat capillary.

$$F(z) = \frac{\pi^2}{6}\frac{k^2}{\mu} nT \frac{\partial T}{\partial x}\left\{1 - \phi\left(\frac{z}{\ell}\right)\right\}. \tag{8}$$

The velocity v(z) of the stationary flow of liquid under the action of such forces in a flat capillary is [4]

$$v(z) = \frac{1}{\eta}\left\{-\frac{\nabla \mathscr{P}}{2} z(d - z) + \frac{\pi^2}{6}\frac{k^2}{\mu} nT \frac{\partial T}{\partial x}\frac{3}{4}\int_0^1 x^2(1 - x^2) \times \right.$$
$$\left. \times \left(1 - e^{-\frac{z}{\ell x}} - e^{-\frac{d-z}{\ell x}}\right) dx\right\}, \tag{9}$$

where η is the viscosity and $\mathscr{P}$ the hydrostatic pressure.

In an open capillary we have $\nabla \mathscr{P} = 0$. Far from the walls ($z/\ell >> 1$) the velocity of the liquid reaches a constant maximum value v_∞. Since $d >> \ell$, it can be assumed that the entire liquid metal, with the exception of a layer with thickness on the order of ℓ, moves with the velocity v_∞

$$v_\infty = 0{,}1 \frac{\pi^2}{6}\frac{k^2}{\mu} nT \frac{\partial T}{\partial x}\frac{\ell^2}{\eta}. \tag{10}$$

For Na and K at $T = 400°K$ and $\partial T/\partial x = 10^2$ deg/cm we have $v_\infty = 10^{-4}$ cm/sec.

If the liquid metal contains solid nonconducting impurity particles, then the electronic thermokinetic forces will cause these particles to move, producing "electronic" thermophoresis.

For particles with radius $r_0 << \ell$ this thermophoresis mechanism can be considered as a particular case of thermodiffusion of impurity atoms under the influence of the electron "wind" [1]. It can be shown that the particle velocity is proportional to their radius r_0. If the thermodiffusion of such particles is characterized by an effective Soret coefficient (S_{eff}), then we get $S_{eff} \sim 10^{-1}$ deg^{-1} for particles with $r_0 \sim 10^{-7}$ cm, whereas the usual values of this coefficient for impurity atoms is $S \sim 10^{-4} - 10^{-2}$ deg^{-1}.

For large particles with $r_0 >> \ell$, the forces causing their motion are concentrated in a layer of thickness much smaller than the particle dimensions. In this case the particle velocity is independent of their dimension and is close in magnitude to v_∞ but of opposite sign. Electronic thermoosmosis and thermophoresis can also take place in liquid semiconductors. If the electron gas is degenerate, then the effect can be calculated as for metals. In nondegenerate semiconductors, the effect is small, since it is proportional to n. The electroosmosis and electrophoresis mechanism described above makes a definite contribution to these phenomena occurring in a gas plasma.

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