Semiconductors with such p-n junctions are tunnel diodes;[2] however, this mechanism for obtaining negative temperatures corresponds to the diffusion, rather than the tunnel, part of the voltage-current characteristic of the tunnel diode.

If the p-n junction is in a strongly degenerate semiconductor, negative temperatures can arise even before the potential barrier is completely destroyed so that quantitative estimates can be obtained with the aid of the theory of the diffusion of current through a p-n junction.

It can be easily shown that the minimum value of the external voltage at which a negative temperature can occur is given by*

$$U_{min} = \Delta/e \quad (2)$$

where $-e$ is the electron charge. The current density I (of the electronic component, for example) is, in order of magnitude,

$$I \approx -(eDn_p/L)\exp(eU/kT), \quad (3)$$

where D is the diffusion coefficient, L is the diffusion length, and n_p is the electron density in the p part of the semiconductor. From formula (3) it can be shown that the current density decreases with increasing degeneracy and decreasing sample temperature. A steady state with negative temperature can thus be obtained. However, the absorption coefficient for radiation in the semiconductor becomes negative at fairly high ($\sim 10^{15}$ cm^{-3}) nonequilibrium concentrations of the minority carriers,[3] and as a consequence it is impossible to work at very low current densities.

The negative temperature occurs in a thin layer near the p-n junction, the thickness of the layer being about a diffusion length. In a degenerate semiconductor the high density of the majority carriers surrounding the region of negative temperature can, apparently, serve as reflecting surfaces, i.e., a "resonating cavity" is formed.

It should be noted that lower current densities can be used if the semiconductors forming the p-n junction have forbidden bands of different widths.

Pankove[4] has observed recombination radiation from p-n junctions in degenerate semiconductors. In a negative temperature state, the concentration of current carriers is lower than in the state having negative absorption coefficient, so that to observe a negative temperature state one should look for changes in the voltage-current characteristic when the sample is illuminated with light of suitable frequency.

*In the case of indirect transitions[3] at low temperatures, the quantity Δ in formula (2) should be replaced by $\Delta - \varepsilon$, where ε is the energy of the radiated phonon.

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RAREFACTION SHOCK WAVES IN IRON AND STEEL

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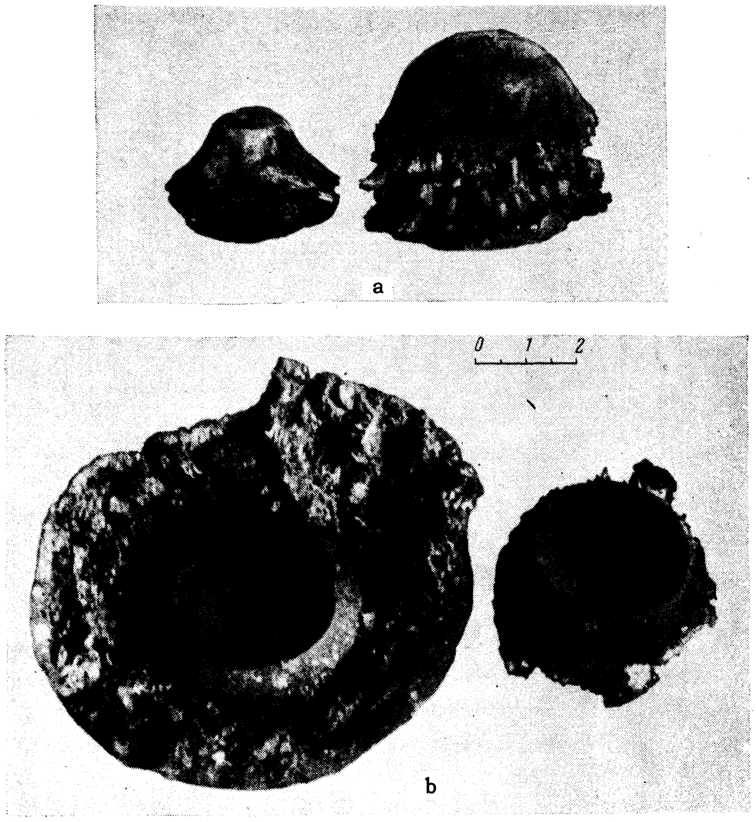
IN the case of a medium with a Poisson adiabat some part of which has a curvature of sign other than the usual one ($\partial^2 p/\partial V^2 < 0$), a rarefaction jump must be introduced in order to construct the rarefaction wave in this region of pressures, whereas a compression jump is impossible.[1] The kink in the shock-compressibility curve in iron at an ($\alpha \to \gamma$) phase-transition pressure of 132,000 atm, noted by Bancroft,[2] is a limiting case of such an anomalous part of the Poisson adiabat.* That a rarefaction jump can in principle be produced in iron was pointed out by Drummond.[3] It is obvious that when rarefaction shock waves interact, destructive stresses will be reached in a very narrow zone, determined by the width of the front of these waves, and this should lead to the appearance of fractures with much smoother surface than in the case when simple rarefaction waves interact.

We have investigated fracture phenomena in cylindrical specimens of steel on whose surfaces explosive charges were detonated. The diameter of the charge was equal to approximately half its length and to the diameter of the specimen. In all cases where the specimens were damaged, fractures were produced near the contact with the charge, in the form of cores of regular geometric shape with smooth surfaces (Fig. 1a and b). In experiments with steel specimens made in the form of rectangular and triangular right prisms, the lower part of each core, as in experiments with cylindrical specimens, was in the form of a



Fractures in the form of cores, obtained in experiments with cylindrical specimens of "Z" steel. Charge of TG 50/50 alloy, 65 mm high. a – "Full" cores. Specimens were 100 mm high and 80 mm in diameter (left) or 120 mm in diameter (right). The base of the cores was in contact with the explosive; b – cut cores. The height of specimen 60 mm, diameter 120 mm. 1 – Cut surface of lower core, 2 – cut surface of upper core (base of upper core was in contact with the explosive).

convex spherical surface, while the lateral surface was similar to that of a rectangular and triangular pyramid. Fractures in the form of cores bounded by a convex spherical surface (Fig. 1a) are formed in experiments with specimens whose heights exceed a certain value for the given charge. As the original height of the specimen is reduced below this value, a new phenomenon is observed: the lower part of the core appears to be cut off in a plane perpendicular to its axis. In the remaining part, the cut cores do not differ at all from the cores with spherical surface ("full" cores). The cut surface is much smoother than the lateral surface of the core. It has the finish produced by a fine cut on a lathe. A second core with a cut (Fig. 1b) is produced in the lower part of the specimen, instead of the usual rear fracture. It should be noted that the "full" cores had approximately half the height of the point where the cut appeared in the specimen. It follows therefore that the spherical core surface is formed some distance behind the front of the compression wave propagating in the specimen.

Similar experiments were also made with copper, brass, and aluminum. None however disclosed fracture phenomena similar to those described above.

The very fact of formation of smooth fractures in steel, the adiabat of which has an anomalous bend at the phase-transition point, enables us to relate the appearance of such fractures with the existence of rarefaction shock waves. From this point of view, the most obvious explanation can be offered for the appearance of cut cores. The cut is produced at the place where the rarefaction jumps meet; one of these jumps occurs in the specimen following the compression shock wave due to the explosion, and the other is produced when this compression wave is reflected from the free surface of the base of the specimen. Calculations carried out by the method of characteristics in the two-dimensional case, using the experimental shock adiabat of iron,[2] are in satisfactory agreement with experiment. On the basis of these experimental data it is natural to attribute the formation of the lateral surface of the core to the interaction between the rarefaction jump in the lateral unloading wave in the specimen and the rarefaction jump that follows the compression wave. Since these jumps collide at a certain angle, it is clear that the zone in which destructive stresses are reached will be broader than in normal collision of the jumps, and consequently the fracture surface will be less smooth than in normal collision. This is in good agreement with experiment.

The mechanism of formation of the spherical surface of the core is still not perfectly clear. The experimental data point to the existence of a connection between the formation of this surface and the rarefaction jump propagating in the specimen behind the front of the compression shock wave.

In the opinion of the authors, these fracture phenomena serve as an experimental proof of the existence of rarefaction shock waves in substances that experience a polymorphic transition under shock loading.

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*Since the iron is not greatly heated by shock compression in the pressure interval under consideration,[2] it can be assumed that the expansion of the iron from the compressed state will follow a curve which differs only slightly from the shock adiabat.

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RECOMBINATION RADIATION FROM INDIUM ANTIMONIDE UNDER AVALANCHE BREAKDOWN

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A number of investigations of the behavior of indium antimonide crystals in strong electric fields have established that at field strengths of ~ 200 v/cm the carrier concentration starts to increase rapidly, owing to the impact ionization of valence band electrons (avalanche breakdown).[1-3]

We have observed infrared luminescence radiation from n type indium antimonide crystals with small impurity concentrations, when pulses with current densities of up to 100 amp/mm^2 were applied. At these current densities the resistance of the specimen was more than an order of magnitude smaller than the resistance at small currents (voltages), which can be ascribed to avalanche breakdown. To avoid heating the specimen, current pulses not more than 3 μsec long were used with repetition frequency 50 cps. The luminescent radiation was observed at a temperature of 78°K, and disappeared when the specimen was warmed up to 120 — 180°K. The rise and decay times of the light pulse did not exceed 1 μsec, so that the observed radiation was not associated with heating of the crystal lattice. The spectrum of the radiation, with a maximum at $\lambda = 5.3\mu$ and half-width 0.25μ, allows it to be assumed that it is recombination radiation.[4] The effective temperature at the maximum of the spectrum was evaluated by comparison with black body radiation, and was 500°K.

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