examined with a high-speed streak camera and proved to be quite satisfactory for practical use. Using this device, determinations of the equation of state and measurements of electrical resistivity have been performed on transition metal oxides and semiconducting III–V compounds.

In the present paper, explosive devices for production of plane shock waves are described in detail, together with several techniques of the shock compression experiments, after a brief summary of shock relations in the next section. The experiments have been performed at Michikawa Laboratory for Explosive Experiments at Iwaki-machi in Akita Prefecture.

II. Basic shock relations

When an ideal plane shock wave travels in a slab of compressible material, a uniformly compressed state is realized behind a shock front, as shown in Fig. 1. The initial undisturbed state and the final compressed state are denoted by subscripts 0 and 1, respectively. The shock of velocity U and pressure P_1 accelerates the material particles to a velocity u_1, causing a density increase from ρ_0 to ρ_1 and an internal energy increase from E_0 to E_1. In a short time Δt the shock front $\mathscr{S}$ travels a distance $U\Delta t$, while the material particles ahead of or behind the shock front travel a distance $u_0\Delta t$ or $u_1\Delta t$, respectively. Therefore the mass flowing in or out of the shock front of unit area during Δt is given by $\rho_0(U-u_0)\Delta t$ or $\rho_1(U-u_1)\Delta t$, which must be equal to each other:

$$\rho_0(U-u_0)=\rho_1(U-u_1)\,. \tag{1}$$

In the same way, the following shock relations[(1),(11)] are obtained from the conservation of mometum and energy across the shock front:

$$P_1-P_0=\rho_0(U-u_0)(u_1-u_0)\,, \tag{2}$$

$$P_1(u_1-u_0)=\frac{1}{2}\rho_0(U-u_0)(u_1-u_0)^2+\rho_0(U-u_0)(E_1-E_0)\,. \tag{3}$$

Using eqs. (1) and (2), the shock compressed state, characterized by P_1 and ρ_1, is determined by the measurement of U and u_1. (Usually $u_0=0$ and $P_0=1$ bar.) A function $\rho_1(P_1)$ is called the Hugoniot equation of state or, for short, the Hugoniot.

Since a direct observation of the particle velocity u_1 is usually difficult, u_1 is indirectly obtained by the measurement of the free surface velocity u_f. At shock pressures up to 500 kbar, the assumption that $u_f\simeq 2u_1$ (the free surface approximation) has been found to be correct for most materials within an error of about 1%[(1)]. To obtain more accurate shock wave data, the impedance match method[(12)] is used: The shock state of the specimen placed on a standard material whose Hugoniot is well known can be determined by measuring only the shock velocities of both the

(11) G.E. Duvall and G.R. Fowles, in *High Pressure Physics and Chemistry*, (R.S. Bradley, ed.) Vol. 2, Academic Press, (1963), p. 209.

(12) J.M. Walsh and R.H. Christian, Phys. Rev., **97** (1955), 1544.

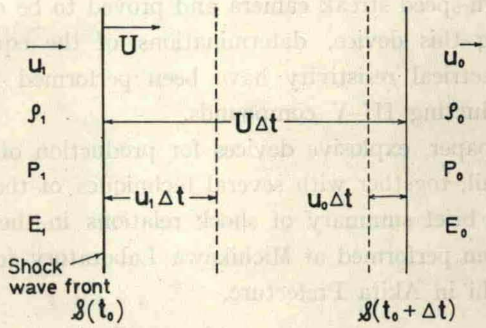

Fig. 1. Progress of a plane shock wave

specimen and the standard material. Usually a shock compressed state is determined by means of both the free surface approximation method and the impedance match method in order to check the experimental results.

Eliminating U and u_1 from eqs. (1)–(3), the increase of the internal energy due to the shock compression is expressed as

$$E_1 - E_0 = \frac{1}{2}(P_1 + P_0)(V_0 - V_1)\,, \tag{4}$$

where $V \equiv 1/\rho$. This equation, called the Rankine-Hugoniot relation,(1),(11) indicates that the shock compression differs from both the isothermal compression and the isentropic compression. The temperature increase due to the shock compression is in general larger than that due to the isentropic compression. However, the shock heating effect in stiff materials which do not undergo crystallographic phase changes is usually neglected at pressures up to about 500 kbar. For example, the temperatures of shocked MgO(13) with an initial temperature of 20°C are estimated to be 102°C at 247 kbar and 212°C at 493 kbar.

III. Production of plane shock waves

Because of the one-dimensionality of basic shock relations, meaningful property measurements in shock wave experiments can only be made in a one-dimensional planar geometry. The explosive plane wave lens can produce plane wave detonation fronts and essentially one-dimensional planar shock fronts in samples. The Snell's-law plane wave lens(14) consists of a conical shell of higher-velocity explosive and a cone of lower-velocity explosive, as shown in Fig. 2. A half of the vertical angle θ is chosen so that the vertical component of the higher detonation velocity D_h is equal to the lower detonation velocity D_l, or

$$\theta = \cos^{-1}(D_l/D_h)\,. \tag{5}$$

(13) T.J. Ahrens, J. appl. Phys., **37** (1966), 2532.
(14) W.B. Benedick, Rev. sci. Instr., **36** (1965), 1309.