TABLE I. Summary of experimental data.

	Elastic shock		Ramp	Main shock	
Distance from impact (mm)	Shock velocity (mm/μsec)	Particle velocity (mm/μsec)	Particle velocity (mm/μsec)	Shock velocity (mm/μsec)	Particle velocity (mm/μsec)
43.9	6.18	0.010	...	...	...
42.0	6.17	0.013	...	(5.6)	0.030
40.1	6.14	0.013	...	(5.6)	0.031
38.2	6.24	0.016	0.028	5.61	0.038
35.6	6.22	0.017	0.038	5.57	0.059
33.1	6.27	0.017	0.037	5.54	0.062
31.6	6.06	0.017	0.038	5.55	0.076
30.3	6.14	0.017	0.037	5.47	0.087
29.0	6.23	0.018	0.039	5.47	0.099
27.9	6.36	0.020	0.040	5.71	0.108
27.0	6.34	0.023	0.052	6.29	0.131
26.2	...	0.032	...	(6.70)	0.154
25.6	6.18	0.035	...	(6.72)	0.161
26.2	6.44	0.027	0.058	6.07	0.143
27.0	6.36	0.023	0.047	6.07	0.130
27.9	6.18	0.023	0.047	5.78	0.113
29.0	6.23	0.021	0.051	5.58	0.112
30.3	6.16	0.020	...	5.34	0.100
	Average 6.23±3%				

and a shock wave breakout that occurs at a local attitude angle θ with the slit projection at the target.

The optical details are omitted for clarity. One objective lens focuses the slit plane onto the film, hence the slit and film planes are shown as coincident. The polished surface is within the field depth of the other objective lens focusing the grid onto the slit plane, hence the camera slit and grid are shown on opposite sides of the polished target with sets of ray paths as parallel lines. The surface is turned at the breakout and is represented by a rotation vector $\boldsymbol{\alpha}$, parallel to the breakout line, and a unit vector $\mathbf{k}$, perpendicular to the target surface. The shock breakout line moves across the target with an apparent shock velocity U_{app}.

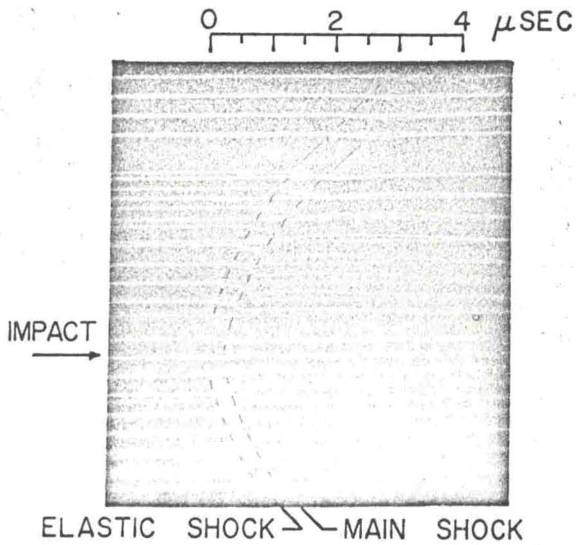

FIG. 5. Photograph of an optical lever record. The two-step shock front shows the elastic shock wave followed by the main shock wave. Lines which show no deflection are camera rewrite indicating a permanent deformation of the target.

Let x, y, z be a rectangular coordinate axis such that x lies along the slit, and z is directed along the optic axis. Each deflected ray is rotated $2\boldsymbol{\alpha}$. The displacement of a ray at the grid plane is

$$2\boldsymbol{\alpha}\times\mathbf{r}=\begin{vmatrix}\mathbf{i} & \mathbf{j} & \mathbf{k}\\ 2\alpha_x & 2\alpha_y & 0\\ 0 & 0 & d\end{vmatrix}=2d\alpha_y\mathbf{i}-2d\alpha_x\mathbf{j}. \quad (17)$$

It is apparent that this relation is similar to the relation

$$\alpha=a/2d \quad (18)$$

described by Fowles, Duvall and Fowles, and by Ahrens and Gregson. Thus the deflection related to turning angle is

$$\alpha=a/2d\cos\theta, \quad (19)$$

and can be used to correct Eqs. (2) and (11) through the appropriate free surface relations for the effect of an off-axis impact. The shock breakout rate along the slit is $U_{\text{app}}\cos\theta$.

B. Results

Figure 5 is an optical lever record obtained by hypervelocity impact of a 2.54-cm-thick target of 2020-T4 aluminum. The projectile was a steel ball 0.636 cm in diameter and struck the target at a velocity of 5.28±0.11 mm/μsec. The elastic shock wave followed by the decaying main shock wave is clearly evident. Table I lists values of measured shock and particle velocity.