taken to examine further the effects of large anisotropic compressions resulting from large values of the HEL[31]. Analytical methods developed in the discussion section give an explicit basis for identification of the loss of shear strength under shock loading. Sapphire is an excellent material for further study because it has similar characteristics to quartz. Both crystals are oxides, both crystals are trigonal; however, sapphire has much larger values for elastic constants. Furthermore, the shear strength effects for sapphire are larger than thermal effects thus affording an uncoupling between mechanical and thermal effects.

Even though the principal interest of this investigation is in the high pressure region above the HEL, measurements were accomplished both below and above the HEL. The measurements below the HEL permit an examination of several elastic constants at compressions an order of magnitude larger than those previously employed and help to guide the extrapolation of the ultrasonic data to the high pressure region.

3. EXPERIMENTAL ARRANGEMENTS

The experiments were of two basic types; those which determined the high pressure response above the Hugoniot elastic limit, HEL, and those which determined the elastic response below the HEL. The high pressure experiments utilized shock-loading with plane wave high explosive techniques, while the elastic response was determined in experiments which utilized projectile impact loading techniques.

The high pressure experiments were accomplished by generating explosively driven plane shock-waves into the samples and monitoring their response with an optical technique similar to that employed by Wackerle[24]. A schematic of this experimental arrangement is shown in Fig. 2. The high explosive plane-wave generators and explosive pads send a shock wave from the detonation through an intermediate driver plate of 2024 aluminum and into the disk-shaped sample. Various pressures are then achieved by the choice of different high explosive materials. The various explosive and impact configurations are described in Table 1.

During the experiment the position of the wire and its image are viewed through appropriate lenses through a 0·1 mm observation slit in the camera and recorded on film as a function of time as the shock wave enters the sample and reflects from the free surface. As the shock enters the sample, the reflectivity of the input surface plating is destroyed and the background light intensity is abruptly changed. An alternate transit time measurement with quartz pins was necessary because of the unreliable nature of the change in reflectivity as the shock entered the sample. The sharp extinction in background light was not always achieved.

After arrival of the second wave the image was sometimes optically distorted as shown in Fig. 2 by the opening of minute scratches on the polished surface. In these cases, however, the scratches themselves or the edge of reflecting surface follow the surface motion directly and their motion was used to obtain second-wave free-surface velocity measurements.

The calibrations of displacement and time are particularly simplified in this technique. The position of the wire above the free surface is measured before shot time to one part in 10^4. The displacement magnitude is then indicated directly on the film by the distance between the wire and its image before shock arrival at the free surface. The rotation speed of the rotating mirror in the camera was measured at shot-time with a resulting sweep rate accurate to $\pm\frac{1}{2}$ per cent. Consideration of all the possible experimental errors in measurements and data reduction gives estimated errors of ±1 to 2 per cent in shock velocity and ±3 per cent in free-surface velocity.

The samples used in the high pressure experiments were cut from single crystal boules of sapphire grown by the Verneuil technique

Table 1. *Shock loading configurations*

Designation	Configuration	Measurements
H	Gun-symmetric impact	impact velocity electrical response
HQ	Gun-quartz gauge	impact velocity quartz gauge signals
B	*P*-40[a] + 25 mm Baratol[b] plus 12 mm 2024 aluminum alloy	free surface velocity (optical) shock velocity (optical/and/or quartz pins)
T	*P*-40[a] + 25 mm TNT plus 12 mm 2024 aluminum alloy	"
C	*P*-40[a] + 25 mm Composition B plus 12 mm 2024 aluminum alloy	"
H	*P*-40[a] + 25 mm PBX 9404 plus 12 mm 2024 aluminum alloy	"

[a] Designation for 10 cm dia. plane wave explosive lens as described in Ref. [5].

[b] Explosive compositions are further described in Ref. [5].

by the Linde Co. The samples were cut, crystallographically oriented, and polished by the Valpey Corporation. The disks were nominally 31 mm in diameter and 6, 10 or 13 mm in thickness. The material was clean and free of defects to the unaided eye. Crystallographic orientations investigated were the natural growth direction of 60°, the optical orientation 0° as well as the 90° orientation.*

Experiments below the HEL were accomplished utilizing the symmetrical projectile impact and electrical response technique previously discussed in some detail[32]. The sample disk is mounted on the impact face of a high velocity compressed gas gun and impacted with a projectile faced with another sample disk. Because of the symmetry of the impacting samples, the particle velocity imparted to the sample is precisely one-half the measured impact velocity. The shock-wave velocity at various particle velocities is measured by observing the electrical response of the sample which is initially charged to a high voltage. The transit time of the shock is clearly indicated on the electrical response records. This experiment is especially useful for determining the shock compression in the elastic range. Experiments beginning at low stress levels and increasing in stress amplitude help to insure the proper identification of the elastic-wave in the high pressure experiments.

One critical projectile impact experiment was performed with Sandia quartz shock-wave stress gauges[33] in which both the impact surface response and back surface response is precisely monitored in time. This type of experiment which has been previously described[34] provides superior time-resolution of the stress profiles in the sample.

4. RESULTS

Measurements and data analysis for shock compression experiments are concerned with the description of the stress vs. time or stress vs. position profiles which result when one surface of a plane sample is subjected to various transient high pressure loadings. The characteristics of these profiles can be shown to be directly related to the stress vs. com-

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*The crystallographic orientation of the 0° axis is $[0001]$, for the 90° axis is $[\bar{1}2\bar{1}0]$ and for the 60° axis is $[11\bar{2}3]$.