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KALISKI'S EXPLOSIVE DRIVEN FUSION EXPERIMENTS

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In this paper I report on an experiment performed by a group in Poland on the production of DD fusion neutrons by purely explosive means. Briefly, they have found means to produce a linear piston motion with a velocity of $5 \times 10_6$ cm/sec, and have used that motion to shock heat and compress D_2 gas to temperatures of 500 eV, with densities of $6 \times 10^{22}/cm^3$, and neutron yields of up to 3×10^7.

The group was headed by Sylvester Kaliski, unfortunately now deceased, who although he held a large number of political and administrative positions, was an exceptionally productive physicist. At the time of his death in September 1958 at the age of 54, Kaliski was a member of the Polish Academy of Science, a member of the Polish Parliament, a member of the Central Committee of the Polish United Workers Party, Minister of Science, Higher Education and Technology in the Polish government, and was Director of the Institute of Plasma Physics and Laser Microfusion in Warsaw. He had been Commander of the Military Academy of Technology from 1969 to 1974 and held the rank of Liuetenant General in the Army. He was founder and Editor in Chief of the Journal of Technical Physics, published entirely in English in Warsaw. In 1977 he published 17 theoretical papers in that journal and was co-author of nine additional papers, mostly experimental. He appears to have started his work in inertial fusion no earlier than 1976. His first papers on the subject appear in 1977.

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*Work performed under the auspices of the U.S. Department of Energy.

The work I wish to discuss here was published in collaboration with others in Refs. 1 and 2. Presumably the experimental work was chiefly done by the others, Derentowicz, Wolski, and Ziolkowski. The first paper is theoretical, while the second is experimental. Derentowicz and Ziolkowski appear to be the principal experimental authors.

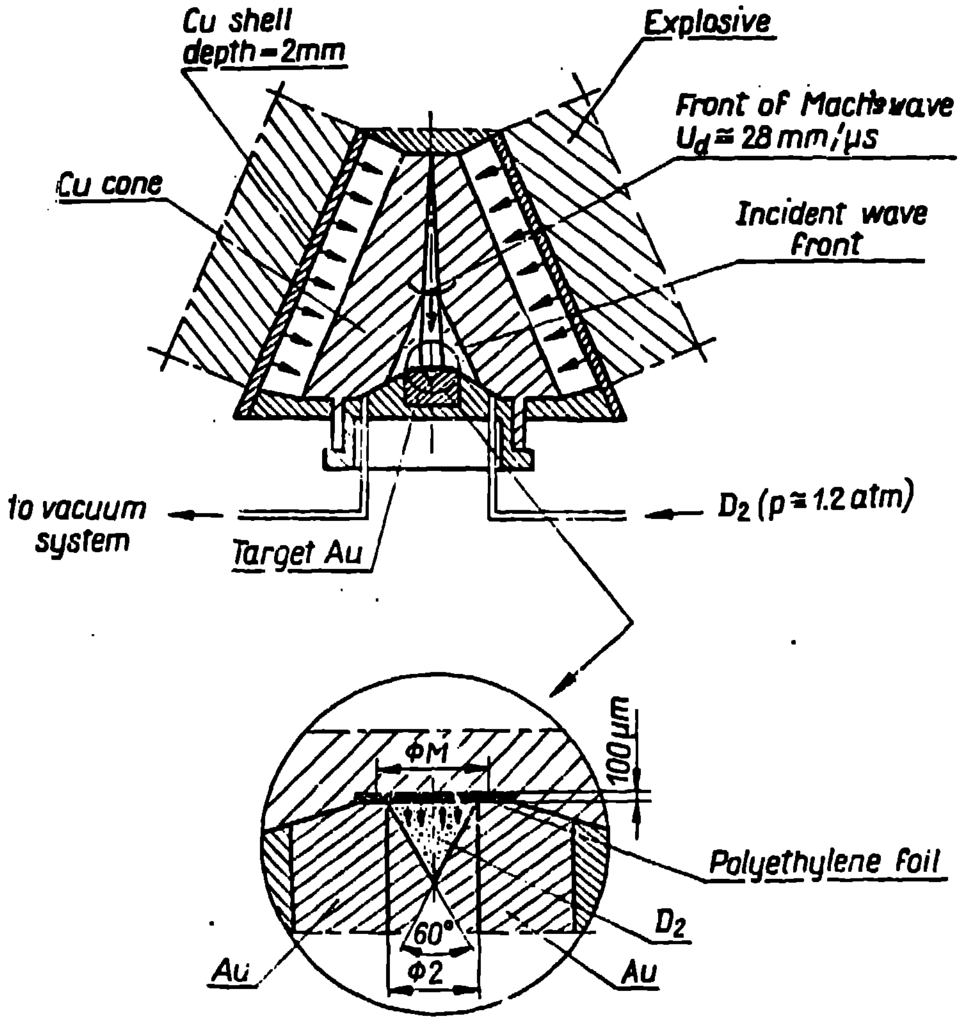

Fig. 1. Experimental Arrangement.

A schematic diagram of the system is given in Fig. 1. A solid copper truncated cone of half-angle is surrounded by a 2-mm thick conical copper liner having the same half-angle. The angle is varied in different shots from 15° to 31°. A vacuum space, several times as thick as the liner separates the liner from the solid copper cone. A hollow conical explosive charge fits closely around the liner. The explosive is fired in such a way that an inward moving detonation wave reaches its entire inner surface as simultaneously as possible. By means of a series of shock waves and rarefaction waves running back and forth through its thickness, the liner is accelerated to a speed of 4 to 5 x 10^5 cm/sec by the time it has crossed the vacuum gap separating it from the surface of the solid cone. The impact of the liner against the cone produces in it a conical shock wave moving inward toward the axis at velocity v_s. The shock wave is stronger than it would have been if the explosive had been directly against the cylinder but sustains its pressure for a shorter time. The convergence of the conical shock toward the axis moves with a phase velocity v_m along the axis of the cone. The axial phase velocity is larger than the velocity of the conical shock by the factor

$$\frac{v_a}{v_m} = \frac{1}{\sin \alpha}$$

Thus, if the cone had a half angle of 30°, the phase velocity along the axis would be twice the velocity of the conical shock.

Under certain conditions, viz. weak conical shock or small cone angle, α , the shock will simply reflect from the axis, so as to form an outward moving conical wave. With strong conical shocks of large enough α, the conical wave is refracted into an axial direction and produces enough pressure to support an axially propagating, nearly plane shock wave at phase velocity v_m. The result is the conical analog of Mach reflection, or a Mach wave. The pressure behind the Mach wave front can be, because of cylindrical convergence, many times larger than pressures in ordinary explosive-driven shocks. In the present experiments, pressures of 30 to 50 megabars (Mb) are generated in a small diameter circular Mach wave. Small cone angles, α, result in larger pressures, see Fig. 2, but in smaller diameter Mach waves, greater sensitivity to small asymmetries in the explosive system, and poorer reproducibility from shot to shot. Characteristics of the Mach wave in cones of three different angles are given in the Fig. 2 and in Table I.

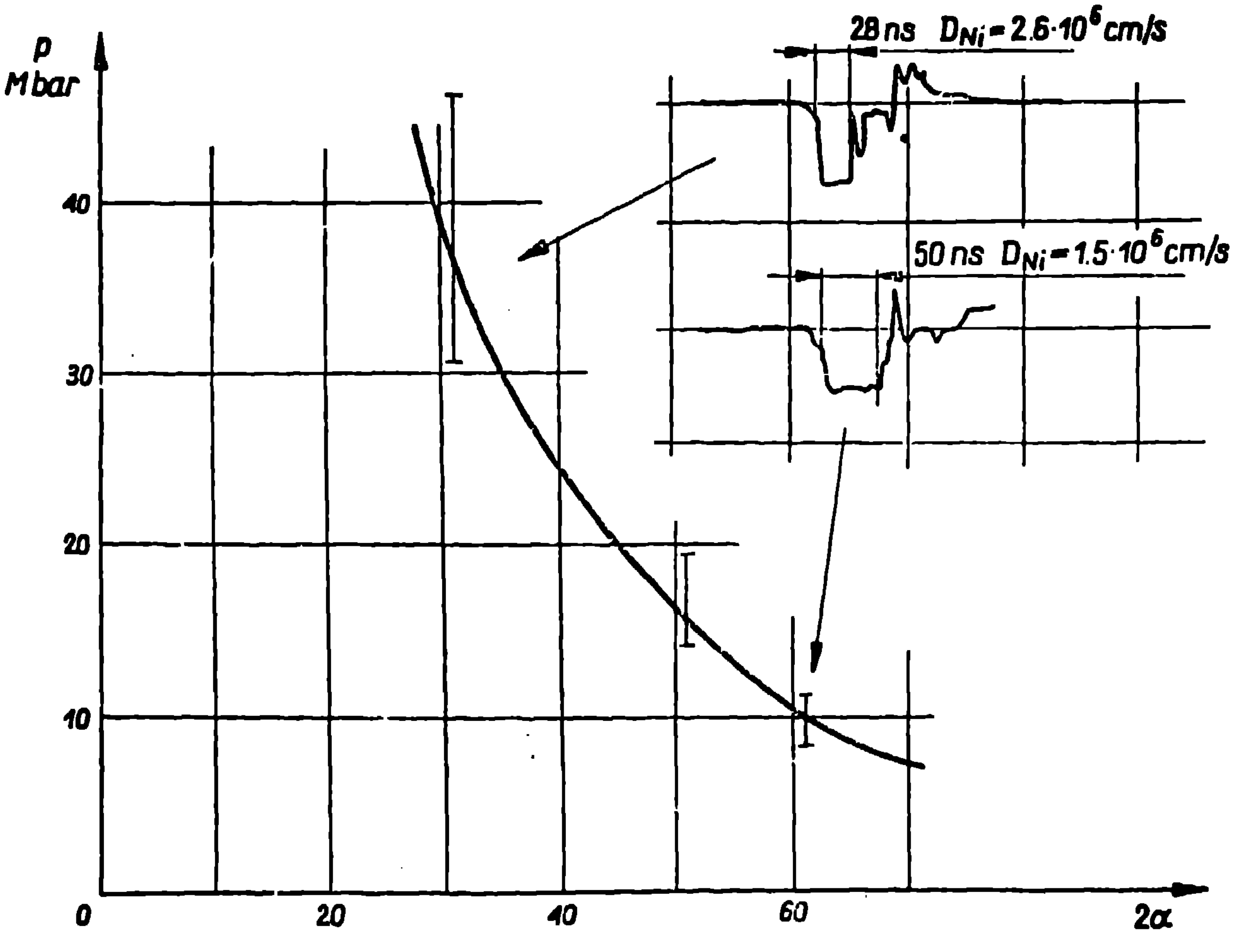

Fig. 2. Cu-Ni thermoelectric probe results and derived shock pressure as function of cone half-angle, .

TABLE I

Mach Wave Characteristics as Function of Cone Half-Angle, .

Angle 2α	Pressure on the Mach wave front [Mb]	Diameter of the Mach wave front [mm	Velocity of the wave front in plexiglass [cm/s]
62°	9.0	7.0	$1.8\cdot10^{6}$
30°	$30\div35$	2.4	$3.5\cdot10^{6}$
36°	30	2.5	—

When a shock wave reaches a free surface, in this case when the Mach wave reaches the base of the solid copper cone, a rarefaction wave is reflected back into the material with a particle velocity parallel to and approximately equal to the particle velocity in the shock. In the present system, the base of the copper cone is not precisely a free surface, but is covered by a thin layer of polyethylene as shown in Fig. 1. The polyethylene is sufficiently soft, relative to the copper that it allows near doubling of the particle velocity, thereby producing a shock in the polyethylene with double the particle velocity of the Mach wave in the copper. On the back side of the polyethylene is D_2 gas at 1.2 bar pressure. Again relative to the polyethylene, this looks like a vacuum, and a further near doubling of the particle velocity occurs.

The D_2 gas is contained in a 30^0 half-angle cone in a small block of gold. The cone is 2-mm in diameter at its base and is sealed against the polyethylene layer, which is 40- m thick. The free surface of the polyethylene compresses D_2 gas ahead of it toward the apex of the cone, with an initial piston velocity of nearly 5×10^6 cm/sec. The D_2 is shock heated and compressed by a factor of about 1000 in volume, achieving an estimated final temperature and density of 500 eV and $6 \times 10^{22}/\text{cm}^3$. Neutrons were recorded on nine shots altogether, with yields varying from 2.5×10^4 to 3×10^7. They ascribe the wide scatter of neutron yields to instabilities in the Mach wave generation process. For every shot with D_2 there was a blank shot without D_2. The blank shots produced no sign of neutrons.

What this group has done is to employ a set of standard (and not so standard) tricks in tandem to multiply the velocities, ordinarily available from high explosives, by a factor of 10 or so. The final piston has a linear motion resembling what we might associate with impact fusion. The linear motion is used to produce a quasi-spherical compression in a conical system.

The shock wave tricks, giving the high velocity, are mostly similar to procedures that have been developed over the years to extend equation of state shock wave measurements to extreme pressures. Direct application of explosive pressures to copper is capable of producing shock particle velocities of 1.5 km/sec, and pressures approaching 1 Mb. The accelerated copper liner reaches speeds of 4 to 5 km/s, producing an intensified conical shock in the solid copper cone with particle velocities of 2 to 2.5 km/sec and pressures of perhaps 1.5 Mb. Similar work has been done in equation-of-state measurements to extend them to 2 Mb. The conical shock waves combine pressure augmentation by cylindrical convergence with an appropriate Mach wave, resulting from the conical arrangement, to bring the pressure to the range of 50 Mb. Equation-of-state work in the USSR has been extended to nearly 10 Mb pressure by the use of plane Mach waves in the work of Al'tshuler, et al. Velocity multiplication by free surfaces follows well extablished techniques in equation-of-state work.

The use of a polyethylene free surface to compress the deuterium and a gold cone to give it quasi-spherical convergence is made practical in these experiments by the relatively low density of the deuterium that is compressed from atmospheric pressure gas rather than from solid or liquid densities. Bremsstrahlung and thermal conduction losses appear to be small enough not to interfere seriously with the compression heating.

The development of the explosive and shock wave techniques employed for velocity augumentation appear to have been the result of extensive experimentation with cylindrical shock waves and axial Mach waves. Some of the measurement techniques had to be developed specially because of the small dimensions involved. One technique (Fig. and Ref. 3) involves the use of a Cu-Ni-Cu thermoelectric gauge, which measures the velocity of the shock directly as it sweeps over a small nickel cylinder. A thermoelectric signal results when the shock sweeps over the Cu-Ni junction and then is canceled when it sweeps over the Ni-Cu junction. The time between the two events, together with the length of the cylinder, gives the shock velocity in nickel. This should be essentially the same as in copper because of the same density.

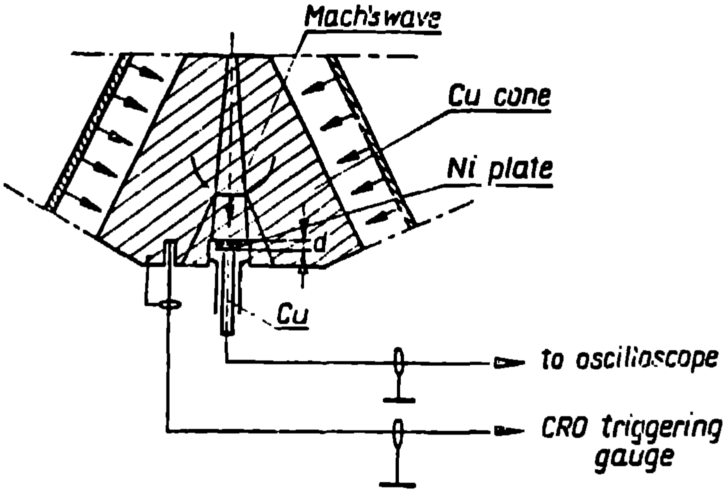

Fig. 3. Cu-Ni-CU Thermoelectric Probe.

Most of the measurement techniques were optical since these required very little change from standard techniques used in equation-of-state work. Typically, these involve light from shocked argon gas layers recorded by streak and framing cameras. Neutrons were measured using scintillators. Optical diagnostics are indicated in Fig. 4.

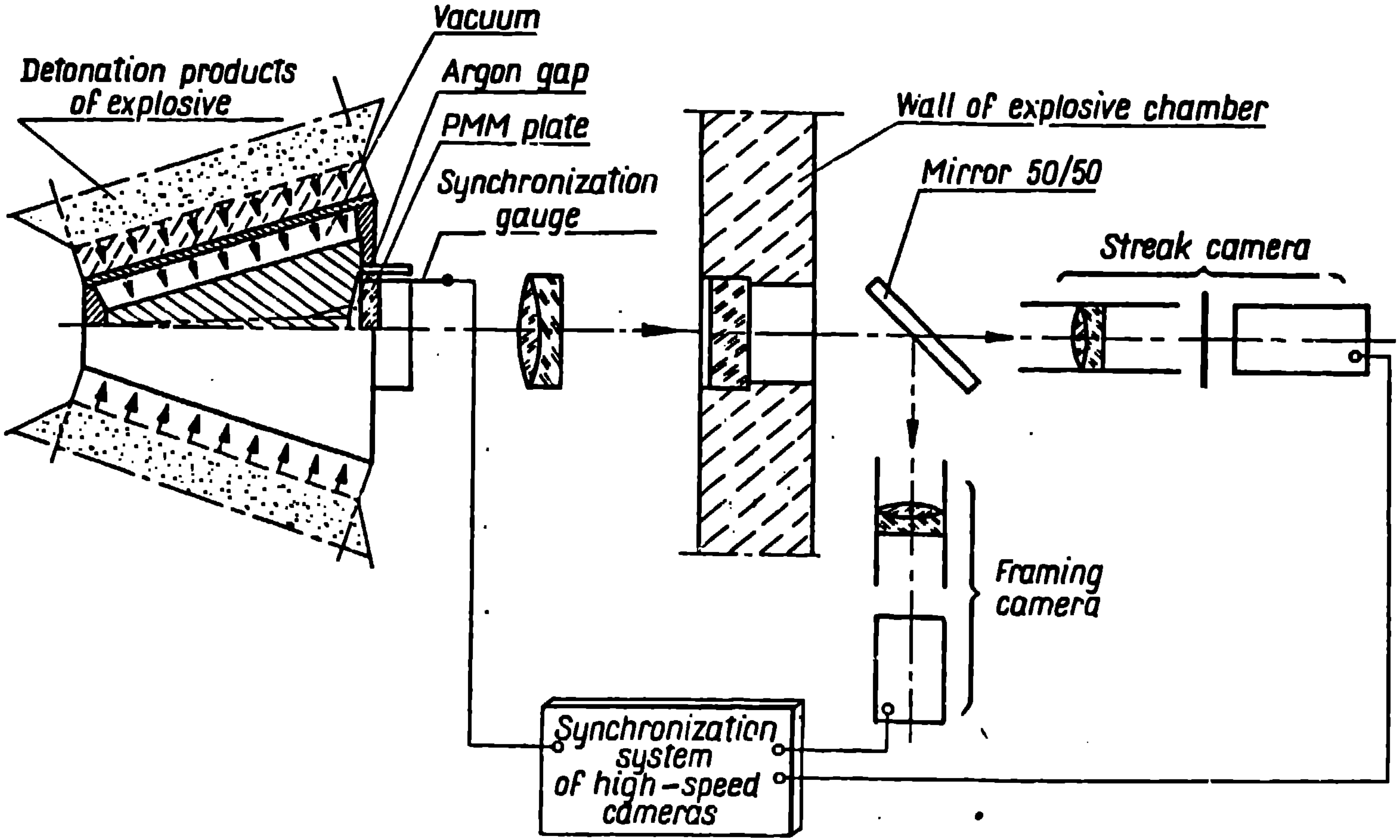

Fig. 4. Opitcal Diagnostics.

References

1. H. Derentowicz, S. Kaliski, and Z. Ziolkowski, "Generation of Fusion Neutrons in a Deuter Filled Cone by Means of Explosive Implosion of Polyethylene Shell, Part I, Theoretical Estimations," Journal of Technical Physics 18, 4, 465 (1977).
2. H. Derentowicz, S. Kaliski, J. Wolski, and Z. Ziolkowski, "Generation of Thermonuclear Fusion Neutrons by Means of a Pure Explosion. II. Experimental Results," Bull. de l'Academie Polanaise des Sciences, serie sciences techniques XXV #10, 135- 897 (1977).
3. H. Derentowicz and Z. Ziolkowski, "Measurement of Parameters of Convergent Cylindrical Shock Waves by Electrical Methods in Metal Samples," Journal of Technical Physics 19, 2, 201 (1978).