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Study of an Ionizing Shock Wave into Transverse Magnetic Fields

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Behaviors of a shock wave in transverse magnetic fields have been studied by Hoffmann, Mashall, Lyubimob, Helliwell and Chu as an interesting problem in magnetohydrodynamics.

The purpose of this research is to solve analytically and experimentally the remarkable phonomena (i.e. the reflected shock wave induced when an ionizing shock wave enters into transverse magnetic fields) and to investigate the reasons of discrepancy of the results between theories and experiments. The ionizing shock wave, in which the gas in front of the shock wave has an electrical conductivity of zero and the one behind it has an infinite conductivity, is treated introducing a modelized ionization temperature by applying Chu's theory.

So, when the fluid temperature is above ionization one, this fluid becomes the magnetically frozen flow. And under these assumptions, we get the fluid velocity and the pressure behind a transverse ionizing shock wave using the conservation equations for a steady one-dimensional flow.

On the other hand, the velocity and the pressure of the fluid propagating into magnetic fields must be equal to the velocity and the total of the gas pressure and the magnetic pressure behind that magnetohydrodynamic shock wave, respectively. So, a reflected shock wave must be induced behind the incident shock wave so as to satisfy the above conditions.

These relations can be given developing the theory of a shock reflection. And supposing that the fluid behind these shock waves becomes thermal equilibrium immediately, the relations of these shock waves with the consideration of ionizing phenomena can be obtained by way of introducing the Saha's equation into the entalpy equation.

For the aim of making sure of above theories we made an experiment using magnetic shock tubes (6 cm in i.d.) which were conical and theta-pinch types. In this experiment, the magnetic fields were made with permanent magnets and assistantly with magnetic coils in which the electric current flowed by a condenser discharge.

The anthor measured the velocities of the shock waves, fluid pressures magnetic fields and electric fields with a streak camera, a piezoelectric pressure transducer, a hole conduction type magnetic probe and an electrical double probe, respectively.

For the reason of the capability limits of the equipment, the conditions of the experiments were restricted within narrow range of initial pressure P_0 from 0.1 to

0.3 mm Hg, of initial magnetic fields B_0 from 0 to 4,000 gauss and of incident shock velocity from 15 to 40 Mach number. The results of the experiments were qualitatively in reasonable agreement with those of the theories.

The velocity of the shock wave in the magnetic fields was larger than of the incident shock wave. The magnetic fields behind the magnetohydroshock wave became larger than initial magnetic fields. The electric fields were induced behind the wave. And the reflected shock wave can be observed at the entrance of the magnetic fields. But generally, these observed values were slightly lower than the theoretical ones. It was observed with the streak camera that the shock front was confined to a radius considerably less than the wall radius of the shock tube.

Next, the author studied the effect of the magnetic diffusion in order to investigate the reasons of discrepancies between experiments and theories. The magnetic Reynolds number of the magnetofluid behind the magnetohydrodynamic shock wave is from 2 to 15.

The author measured the diffusion ratios of the magnetic flux into the incident fluid using the theory of the reflection of the shock wave at a wall in the magnetic fields. These ratios can be calculated with the magnetofluidmechanic diffusion equation assumming that the axial diffusion can be neglected in this experiment. The values of these results at the point of 5 cm from the entrance of the magnetic fields were about 50% at the shock velocity of 30 Mach number.

So, the theories of these experiments cannot be described correctly with above analyses in which the fluid behind the shock waves is the magnetically frozen flow. Considering the effect of the magnetic diffusion it can be said that the theories of an ionizing shock wave into transverse magnetic fields are almost consistent with the results of the experiments.

As a matter of course, these relations of this ionizing shock wave do not break general shock relations studied till now. If the degree of ionization equals to zero, above equations of the shock wave in the magnetic fields become those of transverse ionizing shock theories studied by Chu.

In addition to this condition, assuming that the initial temprature is equal to the modelized ionization temperature, these equations become those of magnetohydrodynamic shock theories studied by Hoffmann, Teller and Helfer.

Supposing the condition of initial magnetic fields at 0 gauss it is calculated with the equations that the velocity of the incident shock wave equals to that of the refracted shock wave into magnetic fields, and then the reflected one becomes a sound wave.

These equations are known as the strong shock relations with ionizing pheonomena which were studied by Bethe, Teller and Iiyoshi.

In addition, if the degree of ionization is zero, the shock relations in this research become Rankine-Hugoniot relations.

And when the initial magnetic field is very large, those equations become the relations of a shock reflection at a wall.