ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

RADIATION FROM A STRONG SHOCK FRONT IN KRYPTON

Reports Control No. OSR-TN-55-184

E. B. Turner

Project 2189

AIR RESEARCH AND DEVELOPMENT COMMAND, U.S. AIR FORCE
CONTRACT NO. AF 18(600)-983, PROJECT NO. R-357-40-6

July 1955

OBJECTIVE

The objective of research under ARDC contract number AF 18(600)-983 has been the study of the hydrodynamics and the spectra behind very strong shock waves produced in a shock tube.

ABSTRACT

Petschek[1] observed that a very strong shock front in argon is usually seen as a bright luminous line. We have shown from wave-speed photographs in krypton with a revolving drum camera at an angle to the shock tube, that the luminosity is homogeneous across the front and not a wall effect. Another series of wave-speed photographs were made with a wedge interference filter placed in front of a horizontal slit on the shock tube. These showed mainly line radiation, but the lines were not those of krypton. At the suggestion of C. W. Peters, a spectrum was obtained by rotating the film drum at such a speed that the image of the shock front was stationary on the film. The Swan bands of carbon, which arise from organic vapors, as well as the lines of Ca and Na were observed. The sharp luminous front is apparently due to inelastic collisions between these vapors and krypton atoms in the zone where translational equilibrium is not yet established.

[1]H. E. Petschek, Phys. Rev. 84, 614(A) (1951).

RADIATION FROM A STRONG SHOCK FRONT IN KRYPTON*

It was first observed by Petschek,** working at Cornell University under Professor Kantrowitz, that for a strong shock wave in argon the shock front appeared as a sharp, luminous line even though there was no luminosity behind the front. For a shock Mach number of 7 he determined that the thickness of the front was less than 0.6 mm.

These luminous shock waves can best be photographed with a revolving-drum camera. A narrow horizontal slit on the side of the shock tube is imaged onto a film drum which revolves at high speed so that the process is spread out in time. The shock wave moving down the tube, therefore, appears at an angle on the film, with the slope proportional to the velocity. Figure 1 shows a photograph of a shock wave in argon moving at approximately eight times the speed of sound. The incident shock appears as a sharp luminous line on the left. One can also see the reflected shock from the end of the tube, which will not be considered in this paper, however. We have found that the luminous shock front occurs in the other noble gases as well and that the thickness of the front decreases with increasing shock strength.

The luminous shock front is, indeed, very curious because it was not predicted by theories of the shock front such as developed by Bond at Los Alamos. One of the most serious difficulties in giving an explanation for the luminosity of the shock front was the lack of experimental evidence. Until recently, for example, no spectra of the front had been obtained. The brightness of the front is fairly high, but it is so thin and travels so fast that it is difficult to obtain enough light for a good spectrum.

In our study of the luminous front, we first tried to determine whether the luminosity is homogeneous across the front or is confined to the side walls of the tube. This point is of crucial importance. The revolving-drum camera was placed at an angle of 8-1/2 degrees from the normal to the tube. If the luminosity were a wall effect we should, therefore, expect to

---

*Supported by the Air Research and Development Command and presented at the 1955 Washington meeting of the American Physical Society.

**H. E. Petschek, <u>Phys. Rev.</u>, 84, 614 (1951).

see two luminous lines, one from each wall. Figure 2 shows a photograph of a shot into krypton at a shock Mach number of about 8. Although the front appears somewhat dim, it can be seen that the luminosity is homogeneous across the front and is not a wall effect.

The next step was to obtain some sort of spectrum of the front. We discovered that a wedge interference filter had recently been put on the market by Bausch and Lomb. The filter is an inch wide and three inches long, and the transmission varies from 4,000Å at one end to 7,000Å at the other, with a band width of about 100Å. Blue spectral lines were found to be transmitted in the red region of the filter, however. For example, the 4,358Å line of mercury was also transmitted at the 6,400Å region of the filter. This filter was placed in front of the horizontal slit on the test section and a revolving-drum camera picture was made in the usual manner. The filter acted as a low resolution spectrograph. The distances along the filter at which light was transmitted depended on the wavelengths of the spectral lines present in the luminosity of the shock front. Figure 3 shows a photograph of a shock front in krypton made in this manner. It can be seen immediately that the spectrum consists of lines rather than a continuum. On the left is a calibration made by photographing a krypton Geissler tube through a wedge filter. Krypton gas was chosen for this experiment because the spots seen through the filter were more distinctive than for argon or xenon. The two spectra obviously do not match, so it must be concluded that the major portion of the luminosity of the shock front is not due to krypton lines but to some kind of impurities. The resolution of the filter was not good enough to identify the impurities, but since the luminosity is homogeneous across the shock front they must be spread uniformly through the gas, which is at a pressure of only 2 cm of mercury.

Figure 4 shows the experimental setup for obtaining spectra of the shock front which was suggested by C. W. Peters at the University of Michigan. The horizontal slit on the side of the shock tube is imaged on a vertical spectrograph slit by means of a lens and a dove prism turned at 45 degrees. The spectrum is then formed on the film drum by the two-prism spectrograph. The camera lens had a speed of f/4.5 and the entire visible spectrum was formed on the 35-mm wide film. As the shock front moves down the tube, its image moves down the length of the slit and its spectrum moves up on the film. If the film drum is rotated at just the right speed the spectrum of the shock front can be made to appear stationary with respect to the film. Thus, the shock front can be followed for a distance down the tube resulting in a large increase in exposure time. Figure 4 shows a spectrum obtained in this manner, but the synchronization was not close enough to define the front clearly. Besides the metallic lines of sodium and calcium, the Swan bands of C_2, and the violet bands of CN were observed in the region behind the shock front before ionization occurred.

The krypton comparison spectrum identifies Kr lines after ionization behind the incident shock. It seems probable that the lines of sodium and calcium result from dirt off the walls which is heated to luminescence by the hot gas behind the shock wave. The luminosity of the front itself must be due to the C_2 and CN bands because the luminosity is homogeneous across the tube. Organic vapors, which would be evenly distributed through the gas, would be broken up by the fast moving atoms at the shock front into C_2 and CN molecules which are excited and radiate. The temperature behind the shock wave is almost 5,000°K for M = 7 and, therefore, the C_2 molecules with a dissociation energy of only 3.6 electron volts are soon dissociated into atomic carbon, which does not radiate so easily. This is offered as an explanation for the sharpness of the luminosity. The continuing presence of the C_2 and CN bands behind the shock front could be due to organic impurities stripped off the walls in the same manner as the sodium and calcium.

Swan bands are known to be very easily excited. They appear in the carbon arc along with CN bands, and in rare gas discharge tubes if any carbon is present.

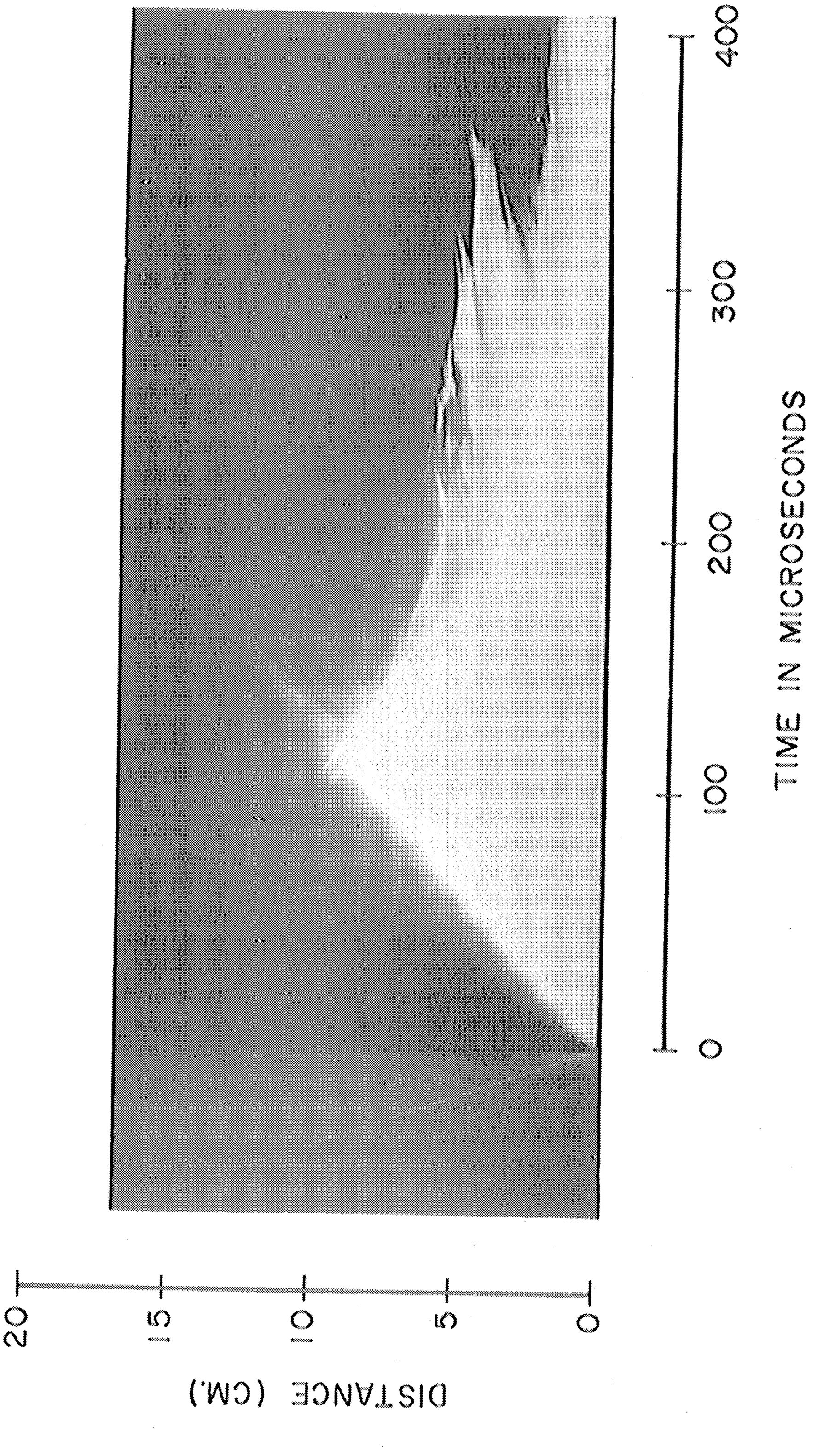
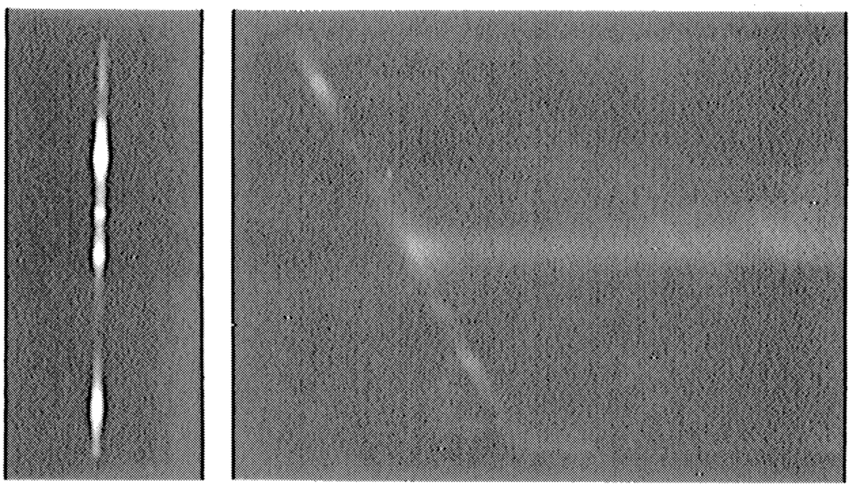


Figure 1

Figure 2



KRYPTON DISCHARGE TUBE COMPARISON

INCIDENT SHOCK IN KRYPTON SEEN THROUGH WEDGE INTERFERENCE FILTER

Figure 3

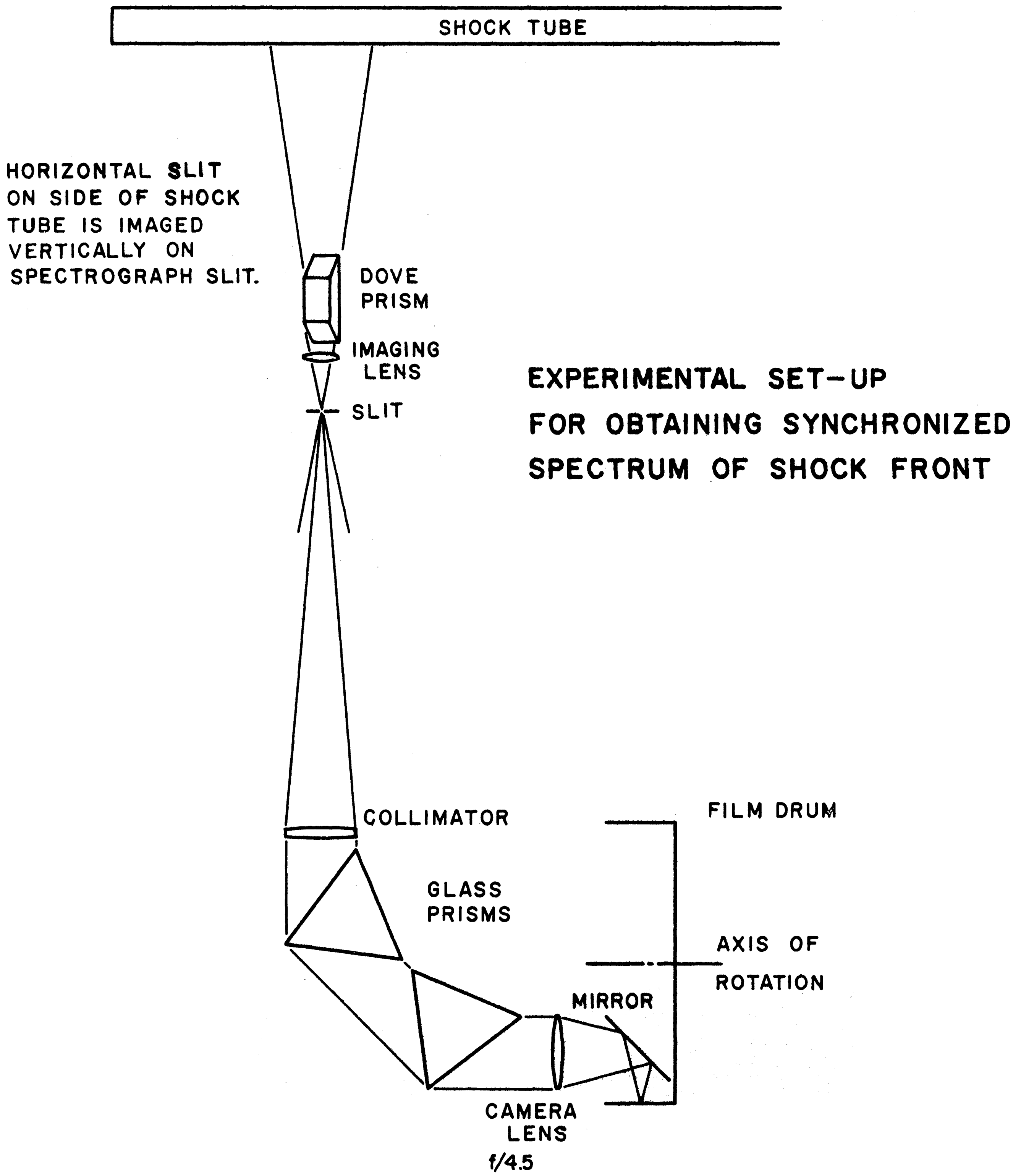

SHOCK TUBE
HORIZONTAL SLIT ON SIDE OF SHOCK TUBE IS IMAGED VERTICALLY ON SPECTROGRAPH SLIT.
DOVE PRISM
IMAGING LENS
SLIT
EXPERIMENTAL SET-UP FOR OBTAINING SYNCHRONIZED SPECTRUM OF SHOCK FRONT
COLLIMATOR
FILM DRUM
GLASS PRISMS
AXIS OF ROTATION
MIRROR
CAMERA LENS
f/4.5

Figure 4

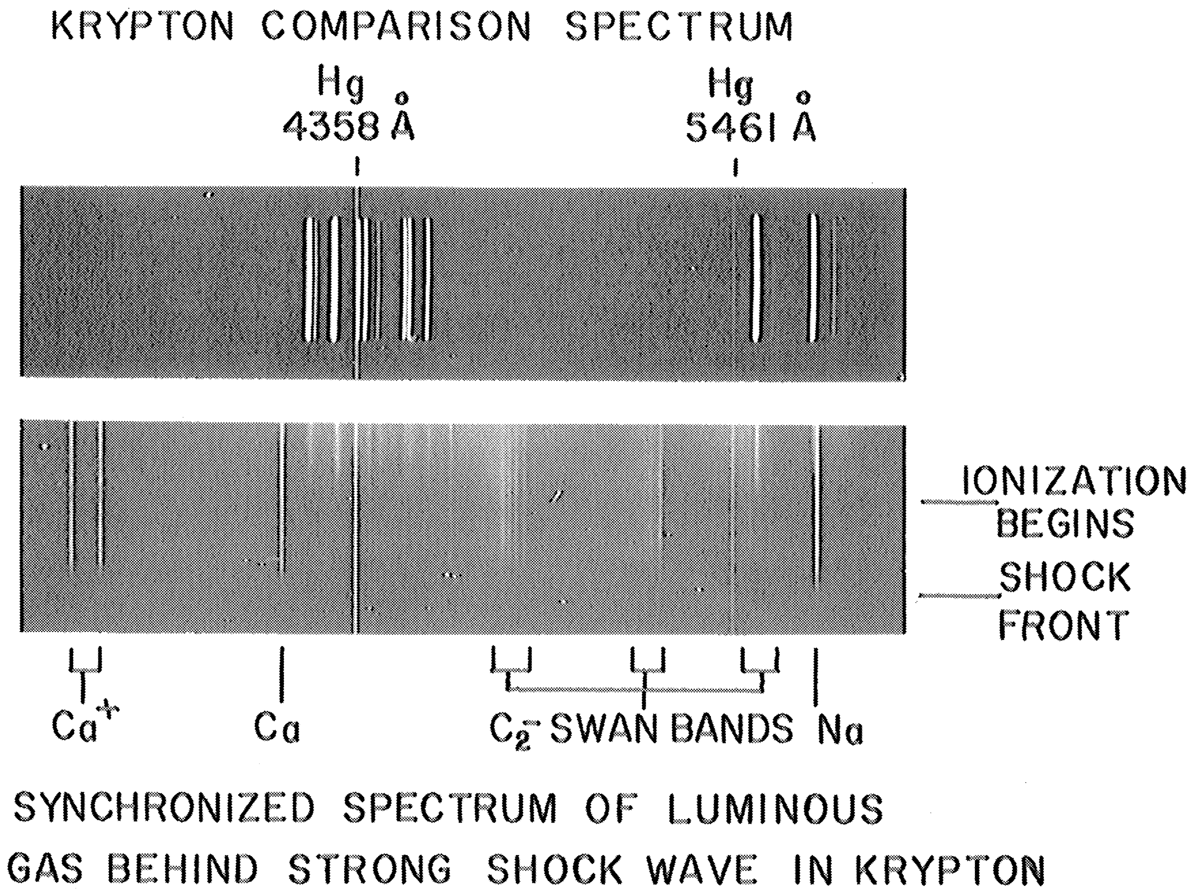

KRYPTON COMPARISON SPECTRUM
Hg 4358 Å
Hg 5461 Å
IONIZATION BEGINS
SHOCK FRONT
Ca+
Ca
C2- SWAN BANDS
Na
SYNCHRONIZED SPECTRUM OF LUMINOUS GAS BEHIND STRONG SHOCK WAVE IN KRYPTON

Figure 5

BIBLIOGRAPHICAL CONTROL SHEET

1. Originating agency and/or monitoring agency:

   O.A.: Engineering Research Institute, University of Michigan, Ann Arbor
   M.A.: Air Research and Development Command, U. S. Air Force

2. Originating agency and/or monitoring agency report number:

   O.A.: ERI Report No. 2189-1-T
   M.A.: Reports Control No. OSR-TN-55-184

3. Title and classification of title: RADIATION FROM A STRONG SHOCK FRONT IN KRYPTON (UNCLASSIFIED)

4. Personal author: Turner, E. B.

5. Date of report: July 1955

6. Pages: 11

7. Illustrative material: 5

8. Prepared for Contract No. AF 18(600)-983

9. Prepared for Project No.: R-357-40-6

10. Security classification: UNCLASSIFIED

11. Distribution limitations: Not to exceed 100 copies

12. Abstract: Petschek[1] observed that a very strong shock front in argon is usually seen as a bright luminous line. We have shown from wave-speed photographs in krypton with a revolving drum camera at an angle to the shock tube, that the luminosity is homogeneous across the front and not a wall effect. Another series of wave-speed photographs were made with a wedge interference filter placed in front of a horizontal slit on the shock tube. These showed mainly line radiation, but the lines were not those of krypton. At the suggestion of C. W. Peters, a spectrum was obtained by rotating the film drum at such a speed that the image of the shock front was stationary on the film. The Swan bands of carbon, which arise from organic vapors, as well as the lines of Ca and Na were observed. The sharp luminous front is apparently due to inelastic collisions between these vapors and krypton atoms in the zone where translational equilibrium is not yet established.

---

[1] H. E. Petschek, Phys. Rev. 84, 614(A) (1951).