

<sup>1</sup>Garwin, Lederman, and Weinrich, Phys. Rev. **105**, 1415 (1957).

<sup>2</sup>Ignatenko, Egorov, Khalupa, and Chultém, J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 1131 (1958), Soviet Phys. JETP **8**, 792 (1959).

<sup>3</sup>I. M. Shmushkevich, J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 645 (1959), Soviet Phys. JETP **9**, 000 (1959); Nucl. Phys. (in press).

<sup>4</sup>Bernstein, Lee, Yang, and Primakoff, Phys. Rev. **111**, 313 (1958).

<sup>5</sup>Shapiro, Dolinskiĭ, and Blokhintsev, Dokl. Akad. Nauk SSSR **116**, 946 (1957), Soviet Phys. "Doklady" **2**, 475 (1957).

<sup>6</sup>Huang, Yang, and Lee, Phys. Rev. **108**, 1340 (1957).

<sup>7</sup>B. L. Ioffe, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 308 (1957), Soviet Phys. JETP **6**, 239 (1958).

Translated by W. H. Furry

185

### GAMMA RAYS ACCOMPANYING THE FISSION OF $U^{238}$ BY 2.8 AND 14.7 Mev NEUTRONS

A. N. PROTOPOPOV and B. M. SHIRYAEV

Radium Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor December 6, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 954-955 (March, 1959)

MOST recent investigations of the prompt fission gammas pertain either to fission of  $U^{235}$ , by neutrons or to spontaneous fission of  $Cf^{252}$ . The latest determinations of the average total energy of the gamma-quanta emitted in one fission yield approximately 7.5 Mev for fission of  $U^{235}$  by thermal neutrons<sup>1</sup> and 8.2 Mev for spontaneous fission of  $Cf^{252}$  (reference 2). It was found experimentally that when  $U^{235}$  is fissioned by thermal neutrons and by neutrons of energies 2.8 and 14.7 Mev, the total energy of the gamma quanta is the same in all cases, within a range of  $\pm 15\%$  (reference 3).

The purpose of this work was to obtain data on the energy liberated in the form of gamma rays during fission of  $U^{238}$  by fast neutrons. Using a procedure and apparatus previously employed,<sup>3</sup> we compared the gamma-ray spectra obtained in the fission of  $U^{238}$  by fast neutrons, with the gamma-ray spectrum obtained in fission of  $U^{235}$  by thermal neutrons. The gamma quanta were registered with a scintillation counter with a

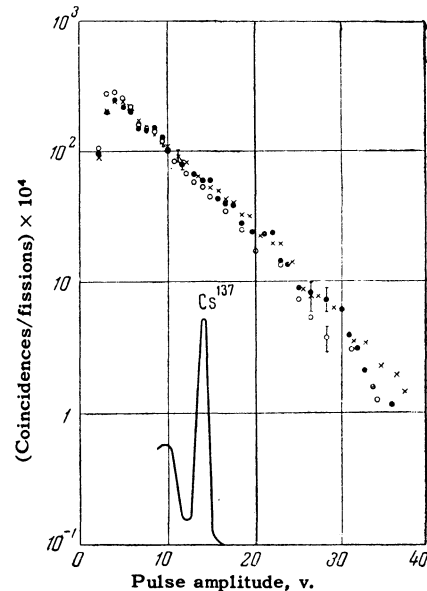


FIG. 1. Distribution of  $\gamma$ -quanta pulses by amplitudes. ● – fission of  $U^{235}$  by thermal neutrons. ○ – fission of  $U^{238}$  by 2.8-Mev neutrons. × – fission of  $U^{238}$  by 14.7-Mev neutrons.

NaI(Tl) crystal, connected for coincidence with a single-layer fission chamber that registered the fissions. Placed in the chamber were targets of equal diameter made of  $U^{235}$  and  $U^{238}$  with an average density of 1.8 and 2.2 mg/cm<sup>2</sup> respectively. The relative placement of the crystal and of the layers of the fissioning substance was the same for thermal and fast neutrons. The spectra of the pulses obtained from the scintillation counter, after eliminating the random coincidences, are shown in the diagram. To estimate the values of the energy, the abscissa of the diagram shows the amplitude distribution of the momenta for gamma rays of 661 keV energy ( $Cs^{137}$ ). The ratio of the number of coincidences between gamma quanta and fragments obtained by fission of  $U^{238}$  by 2.8 and 14.7 Mev neutrons to the number of coincidences for fission of  $U^{235}$  by thermal neutrons, are respectively  $1.03 \pm 0.03$  and  $1.00 \pm 0.02$ . For the measured range of amplitudes, as can be seen from the diagram, the spectra have the same appearance for all cases. Taking account, however, of the fact that the indeterminacy in the final results is greater, owing to the possible divergence of the spectra at large energies, one can conclude that in the fission of  $U^{238}$  by 2.8 and 14.7 Mev neutrons the average total energies of the gamma rays are the same, within 15%, as in the case of fission of  $U^{235}$  by thermal neutrons.

In comparing the data obtained with the results of other investigations we see firstly, that the average total gamma-quanta energies per fission are nearly equal for all the investigated nuclei ( $U^{235}$ ,

$U^{238}$ , and  $Cf^{252}$ ). Secondly, the gamma quanta energies depends little on the excitation energy of the compound nucleus prior to fission.

The authors express their gratitude to Yu. I. Belyanin for insuring operation of the accelerated tube in the performance of this experiment.

<sup>1</sup>R. B. Leachman, Phys. Rev. **101**, 1005 (1956). Artem'ev, Protopopov, and Shiryaev, Труды РИАН (Trans. Radium Inst. Acad. Sci.) **9**, in press.

<sup>2</sup>Smith, Fields, and Friedman, Phys. Rev. **104**, 699 (1956).

<sup>3</sup>A. N. Protopopov and B. M. Shiryaev, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 331 (1958), Soviet Phys. JETP **7**, 231 (1958).

Translated by J. G. Adashko  
186

### ZEMPLEN'S THEOREM IN RELATIVISTIC HYDRODYNAMICS

R. V. POLOVIN

Physico-Technical Institute, Academy of Sciences, Ukrainian S.S.R.

Submitted to JETP editor December 12, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 956 (March, 1959)

KHALATNIKOV<sup>1</sup> has shown that for a relativistic shock wave of low intensity the theorem of Zemplen and the conditions of mechanical stability,  $v_1 > c_1$ ,  $v_2 < c_2$ , are applicable provided only that the following inequality holds;

$$\left(\frac{\partial^2(w/n)}{\partial p^2}\right)_s > 0 \quad (1)$$

(where  $w$  is the heat function per particle,  $s$  the entropy per particle,  $n$  the density of particles measured in the rest system of the particles, and  $p$  the pressure.)

These results are also applicable for relativistic shock waves of any intensity. The proof can be done in a similar way to Landau and Lifshitz, (reference 2, paragraph 84,) for the case when the shock adiabate lies in the plane ( $p, w/n$ .) In this case, formula (84,6) will correspond to

$$w_2 T_2 ds_2 = \frac{1}{2} (w_1/n_1 - w_2/n_2)^2 d(j^2),$$

and the expression

$$1 - \frac{v_2^2}{c_2^2} = (V_1 - V_2) \left[ 1 - \frac{j^2 (V_1 - V_2)}{2T_2} \left( \frac{\partial V_2}{\partial s_2} \right)_{p_2} \right] \frac{d(j^2)}{dp_2}$$

is replaced by

$$1 - \frac{u_2^2}{a_2^2} = \left( \frac{w_1}{n_1} - \frac{w_2}{n_2} \right) \left[ 1 - \frac{j^2 (w_1/n_1 - w_2/n_2)}{2w_2 T_2} \left( \frac{\partial (w_2/n_2)}{\partial s_2} \right)_{p_2} \right] \frac{d(j^2)}{dp_2},$$

$$j = nu, \quad u = v/\sqrt{1-v^2}, \quad a = c/\sqrt{1-c^2},$$

(where  $c$  is the velocity of sound, and the velocity of light is taken as unity.) It follows from this that the quantity  $n/w$ , as well as the pressure and the density, are increased on the shock wave.

The inequality (1), for the nonrelativistic case, reduces to the well known conditions,  $(\partial^2(1/n)\partial p^2)_s > 0$ . For a relativistic ideal gas we have

$$\left(\frac{\partial^2(w/n)}{\partial p^2}\right)_s = \frac{2(2-\gamma)}{\gamma(\gamma-1)} \frac{1}{pn^2}.$$

The last expression is always positive, since the quantity  $\gamma$  is within the interval<sup>3</sup>  $1 < \gamma \leq 5/3$ .

It should be noted that for an ultra-relativistic ideal gas,<sup>2</sup>  $\gamma = 4/3$ .

The author wishes to thank A. I. Akhiezer and G. Ya. Lyubarski for valuable discussions.

<sup>1</sup>I. M. Khalatnikov, J. Exptl. Theoret. Phys. (U.S.S.R.) **27**, 529 (1954).

<sup>2</sup>L. D. Landau and E. M. Lifshitz, Механика сплошных сред (Mechanics of Continuous Media), GITTL, M. 1954.

<sup>3</sup>A. H. Taub, Phys. Rev. **74**, 328 (1948).

Translated by S. Kotz  
187

### ON ELECTROMAGNETIC SHOCK WAVES IN FERRITES

A. V. GAPONOV and G. I. FREIDMAN

Radiophysics Institute, Gorkiĭ State University

Submitted to JETP editor December 18, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 957-958 (March, 1959)

WE investigate the propagation of a uniform plane electromagnetic wave in a medium with non-linear dependence of the induction  $\mathbf{B}$  on the magnetic field  $\mathbf{H}$ .\* We assume to begin with that the