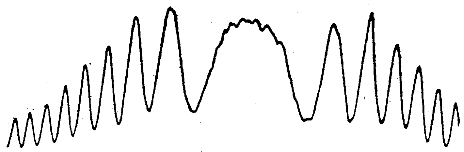

FIG. 1. Microphotometric record of the Be I line λ4573A.

Wagner[1] (0.030A). My supposition is that Parker took a microphotometric record of a fringe of too low an order in the interference pattern where the distribution of intensity in a single fringe is deformed by the very rapid falling of the intensity in the direction to the middle of the pattern. In view of the results of my experiments and of the work of Ballard, Anderson and White[4] on the Be III spectrum the conclusion is that if the beryllium nucleus has a magnetic moment different from zero, it must be very small, much smaller than it was supposed by Parker. The weak component of the Be II line 4673A found by Kruger and Wagner is probably due to a foreign line.

S. MROZOWSKI

Institute of Theoretical Physics,
Joseph Piłsudski University,
Warsaw, Poland,
October 4, 1938.

[1] P. G. Kruger and R. C. Wagner, Phys. Rev. **41**, 373 (1932).
[2] A. E. Parker, Phys. Rev. **43**, 1035 (1933).
[3] R. Ritschl, Zeits. f. Physik **79**, 1 (1932).
[4] S. S. Ballard, O. E. Anderson and H. E. White, Phys. Rev. **47**, 256 (1935).

Instantaneous Emission of Fast Neutrons in the Interaction of Slow Neutrons with Uranium*

Recently it became known[1] that uranium can be split by neutrons into two elements of about equal atomic weight. In this fission of uranium the two elements produced have a large neutron excess; moreover they are probably produced in an excited nuclear state. One might therefore expect that these excited fragments instantaneously emit neutrons and that perhaps the number emitted is even larger than one per fission.

One might also expect a delayed emission of neutrons—as was first pointed out by Fermi—if some of the fragments go through one or more beta-transformations before they emit a neutron. Delayed emission of neutrons caused by the action of both slow and fast neutrons on uranium has recently been reported by Roberts, Meyer, and Wang,[2] who find a period of about 12 seconds.

In order to see if there is an instantaneous emission of neutrons from the fission of uranium we have performed the following experiment. We exposed uranium oxide to neutrons which were slowed down by paraffin wax, using as a source of neutrons a block of beryllium from which photoneutrons were liberated by the gamma-rays of radium. A helium-filled ionization chamber connected to a linear amplifier served as a detector for fast neutrons. The ionization pulses of the chamber were observed visually by means of a cathode-ray oscillograph and were recorded by the usual counting arrangement.

Figure 1 shows a diagram of the experimental arrangement. The ionization chamber is covered by a cadmium sheet cap G which prevents the thermal neutrons from penetrating to the helium ionization chamber. A cadmium sheet shield H, 0.5 mm thick, is used to cover the cylindrical box E which contains 2300 g of uranium oxide. The uranium oxide is screened from the thermal neutrons by this shield and can be exposed to them simply by removing the shield.

We observed about 50 pulses per minute from the helium chamber when we exposed the uranium oxide to the thermal neutrons in the absence of the cadmium shield H, but obtained only 5 pulses per minute when the uranium was screened from the thermal neutrons by the cadmium shield. The difference of about 45 pulses per minute we have to attribute to fast neutrons emitted from uranium under the action of thermal neutrons. It is reasonable to assume that this emission of fast neutrons is connected with the fission of uranium.

Control experiments were carried out in which uranium was replaced by lead. The effect of the presence and absence of the cadmium shield H and the cadmium cap G was tested.

In order to estimate the number of fast neutrons emitted per fission under the action of thermal neutrons we used an ionization chamber lined with a thick layer of uranium oxide having an area of 25 cm^2. This uranium chamber was put in place of the helium chamber without otherwise materially changing the experimental arrangement. Under these conditions the uranium chamber gave about 45 fissions per minute. Assuming the range of the fission fragments to be about 0.005 g per cm^2 in uranium oxide, the observed 45 fissions per minute should occur in a surface layer, weighing 0.13 g, of the thick uranium oxide lining. Accordingly, about 800,000 fissions per minute should occur in the 2300 g of uranium oxide which was used in our experiment. By taking into account the solid angle, the size of the helium chamber and the pressure used, and by assuming that the "fission neutrons" have an average collision cross section in helium of 3.5×10^{-24} cm^2 we find the number of neutrons emitted per fission to be about two.

This number is of course only a rough estimate; the main cause of uncertainty is the considerable variation of the cross section of helium with the neutron energy in

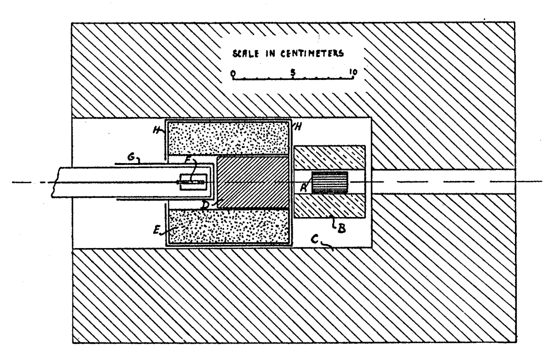

FIG. 1. Arrangement for the observation of the emission of fast neutrons from uranium. A, Radium. B, Beryllium block. C, Paraffin wax. D, Lead block. E, Box filled with uranium oxide. F, Ionization chamber. G, Cadmium sheet cap. H, Cadmium sheet shield.

the region around one million volts.[3] A hydrogen-filled ionization chamber is now being used in order to obtain a more accurate estimate. It seems to be established, however, that the order of magnitude is one neutron per fission.

Anderson, Fermi and Hanstein have independently, and by a different method, carried out experiments on the neutron emission connected with the fission of uranium. Our observations are consistent with their results, and we wish to thank them for communicating their results to us before publication.

While from our observations we can only say that the time delay involved in this "instantaneous" neutron emission appears to be less than one second, we should expect, for theoretical reasons, this emission to take place within less than 10^{-14} second.

We have also looked for a delayed emission of fast neutrons by performing the following experiment. The uranium oxide was irradiated for some length of time in the arrangement shown in Fig. 1. Then the radium was quickly removed from the beryllium block and the cathode-ray oscillograph screen was watched for a period of 15 seconds for an indication of a delayed emission of fast neutrons. After the radium is removed there is no gamma-ray background to set a lower limit for the observable helium recoil energy; the only slight background remaining is due to electrical fluctuations of the amplifier. In 50 experiments, corresponding to a total observation time of more than 12 minutes, we observed only two pulses which may or may not have been due to a delayed emission of fast neutrons. This is to be compared with the emission of 45 fast neutrons per minute, the number observed while the radium is inside the beryllium block. We conclude that, if slow neutrons falling on uranium cause a delayed emission of neutrons which are sufficiently fast for us to observe, their number must be very much smaller than the number of neutrons which we have observed in the instantaneous emission.

We are indebted to Dr. S. Seely for his assistance in carrying out some of these experiments. We wish to thank the Department of Physics of Columbia University for the hospitality and the facilities extended to us, and also wish to thank the Association for Scientific Collaboration for enabling us to use one gram of radium in these experiments.

Leo Szilard
Walter H. Zinn

Pupin Physics Laboratories,
Columbia University,
New York, New York,
March 16, 1939.

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[1] O. Hahn and F. Strassmann, Naturwiss. **27**, 11 (1939); L. Meitner and R. Frisch, Nature (February, 1939).
[2] R. B. Roberts, R. C. Meyer, and P. Wang, Phys. Rev. **55**, 510 (1939).
[3] H. Staub and W. E. Stephens, Phys. Rev. **55**, 131 (1939).