PENETRATING RADIATION FROM PULSE DISCHARGES

L. A. Artsimovich, A. M. Andrianov, E. I. Dobrokhotov,
S. Yu. Lukyanov, I. M. Podgorny, V. I. Sinitsyn, N. V. Filippov

We present the results of an investigation of the neutron radiation detected in pulse discharges in deuterium, as well as some data on the penetrating X-ray radiation that arises in such discharges in light gases.

Intense current pulse discharges in light gases can, under some conditions, act as sources of penetrating radiation. In 1952 the authors discovered neutron radiation in pulse discharges in deuterium. The experiments in which this phenomenon was discovered were performed with straight discharge tubes. The tubes were porcelain cylinders (with diameters from 20 to 40 cm and 50 to 100 cm long) with copper or dural collars. They were connected to a circuit consisting of a bank of condensers and spherical dischargers. When the pulse discharge takes place, a current of several hundred kiloamps passes through the tube. The rate at which the current increased was \(5 \times 10^{11}\) to \(1.5 \times 10^{12}\) amp/sec. In the original experiments the neutrons were recorded by the use of silver targets placed in a paraffin block located close to the tube. In later experiments, the neutrons were observed by use also of scintillation counters, and it was then possible to establish the connection between the time at which the neutrons appear and the characteristics of the pulse discharge.

Neutron emission is observed in discharge tubes with porcelain walls if the initial pressure of the deuterium is within the range of 0.01 to 0.3 mm. In tubes with metallic side walls, neutrons are emitted also for considerably higher initial pressures, up to 10 mm. The number of neutrons that are emitted while the current is passing through the tube fluctuates widely from one discharge pulse to another. In the experiments with the porcelain discharge tubes, the neutron emission reaches measurable values only if the tube has been first subjected to previous discharges in hydrogen, deuterium, or helium. For a maximum discharge current from 250 to 500 kiloamps and for an initial deuterium pressure of about 0.1 mm, the number of neutrons emitted in one discharge pulse varies between the limits of \(10^2\) and \(10^4\), sometimes reaching a value of the order of \(10^6\). The neutron radiation is extremely sensitive to the addition of small quantities of different gases. It is enough to add a few hundredths of a percent of hydrogen, argon, or xenon to deuterium to a pressure of 0.1 mm, for the neutron radiation to vanish entirely.

Because of the irregularities of the neutron radiation, it is difficult to establish quantitative relations that characterize the dependence of the neutron emission on such discharge parameters as the maximum current and the initial pressure. These relations are somewhat more qualitative than quantitative in character. Figure 1 shows the dependence of the neutron emission \(n\) on the maximum current in the discharge \(I_{\text{max}}\), obtained in experiments with a porcelain discharge tube 100 cm long and 40 cm in diameter at an initial pressure of 0.02 mm.

This data is obtained by averaging the results of a large number of separate experiments. We see that the intensity of neutron emission increases rapidly with the maximum discharge current from 200 ka to 300 ka. For further increase of \(I_{\text{max}}\) the value of \(n\) hardly changes. It should be noted that in these experiments the value of \(I_{\text{max}}\) is proportional to the initial voltage on the discharge tube. A change in \(I_{\text{max}}\) from 206 to 400 ka corresponds to an increase in the initial voltage from 20 to 40 kv. Similar curves of the dependence of \(n\) on \(I_{\text{max}}\) are obtained also at other pressures. The pressure that corresponds to the maximum neutron emission for
Oscillographic studies of the neutron radiation show that in all cases it occurs in the form of short pulses with very sharp fronts. The length of time it takes for the neutron radiation to grow from zero to the maximum value is 0.3-0.5 μsec. The neutron pulses appear at definite stages of the development of the discharge. In a previous communication [1], as well as in the work of M. A. Leontovich and S. M. Osovets [2], it is shown that in the first half period of the development of the pulse discharge, successive contractions and expansions of the plasma column take place. These processes are reflected in the oscillograms of the current and voltage during discharge. At that instant of time when the discharge filament passes through the stage of maximum compression, there appears a kink on the current oscillogram. The voltage at this time has reached its maximum value and starts to drop rapidly.

Figure 2 is an oscillogram of the current and neutron pulses taken with the aid of a double beam oscillograph. One of the oscillograph traces is that of the current variation, measured with the aid of a Rogovsky bridge, and the other trace is the neutron radiation intensity, recorded with the aid of a scintillation counter and a photomultiplier. As is seen from this oscillogram, (on which the neutron pulse is presented with a delay of 0.3 μsec), the neutron emission starts at a time corresponding to the second stage of maximum contraction of the plasma column. This is not a chance result, but represents a well established regularity. Analysis of an extremely large number of oscillographic measurements shows that in all cases the neutron emission starts at that part of the discharge in which the plasma column passes through the second stage of maximum contraction. In the first contraction neutrons appear. At low initial pressures in tubes of large diameter, three successive contraction and expansion stages of the discharge filament are observed. For these conditions neutrons sometimes arise both in the third, as well as the second maximum of filament contraction.

A pulse discharge with a rapid rate of current increase is also a source of penetrating X-radiation. The X-radiation always consists of short pulses whose rise time is a few tenths of a microsecond. The pulses caused by X-ray quanta and neutrons during deuterium discharge can be compared on the oscillograph. In so doing, it turns out that they arise simultaneously. The energy of the X-ray quanta that occur during discharge in hydrogen and deuterium attain values of 300-400 kev. It should be noted that at the time when quanta of such high