orbits in the simplest Bohr model of the atom, it is necessary to satisfy the following condition. The perimeter of the stationary orbit must be equal to an integer number of de Broglie wavelengths. In other words, of stabler orbits there should be a resonance of the traveling wave propagating along the closed loop.

This conclusion can be simulated with the aid of 3-cm magnetic waves. The fact that the resonance phenomenon is indeed observed for a traveling wave propagating in a closed loop, when the length of the contour is suitably chosen, it can be demonstrated in the following manner (Fig. 6).

A waveguide ring is assembled of 3-cm waveguide sections of different shape, connected in series with a directional coupler DC, a three-cm measuring line ML, and a dielectric phase shifter φ. Low-frequency (400 Hz) amplitude-modulated 3-cm electromagnetic waves enter into the ring from a generator G, the waveguide output of which is connected to the input of the directional coupler. A dielectric phase shifter, similar to that described in the demonstration I (Phase Control of the Interference Pattern), makes it possible to vary the electrical length of the loop. The detector in the measuring-line probe registers the amplitude of the wave at the given point of the loop. The detected signal from the probe is fed through a low-frequency amplifier to the input of an EO-7 oscilloscope.

The phase shifter is first set at zero. A signal of small amplitude is observed on the oscilloscope screen, since a loop of arbitrary length does not span an integer number of waves, and the waves concel eath other. By rotating the knob of the phase shifter, a position is found such that the signal amplitude passes through a maximum. This corresponds to the case when the loop spans an integer number of waves. It can be verified

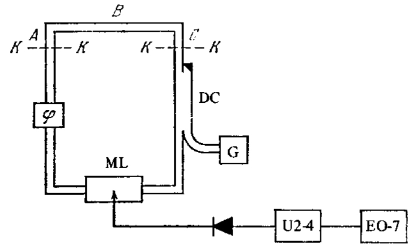

FIG. 6

that a traveling wave exists in the contour in both cases for the variations of the signal amplitude are negligible when the probe is moved along the line. They are due to the non-ideal joining of the individual parts of the loop. Thus, the experiment has shown that resonance can occur for a traveling wave under certain conditions.

Let us open the waveguide loop, removing from it the section ABC, and let us short the open outputs of the waveguides with metallic plates KK. A standing wave is established in the line. When the probe is moved along the line, the signal on the oscilloscope screen changes periodically from zero (nodes of the standing wave of the electric field) to a maximum (antinodes of the standing wave).

Of course, during the demonstration it is necessary to describe carefully the difference between de Broglie and electromagnetic waves, and to state that the task of the experiment is only to present a model of de Broglie's ideas.

The authors are sincerely grateful to Professor N. N. Malov for valuable hints and for help with the work on the demonstrations.

ILLUSTRATION OF X-RAY PHOTOGRAPHY OF A ROTATING CRYSTAL WITH THE AID OF CENTIMETER ELECTROMAGNETIC WAVES

538.56

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WE describe in this paper two variants of a lecture demonstration that illustrates with the aid of centimeter waves the production of an x-ray pattern by the rotating-crystal method. The validity of the Bragg law for these waves was first experimentally demonstrated in the early Twenties by N. A. Kaptsov.[1-2]

The setup (Fig. 1) comprises a commercial 3-cm generator 1 with a power supply 2, a receiving horn antenna 3 connected to an oscilloscope S-1, and a crystal model 4, consisting of 477 copper dipoles, the natural frequency of which coincides with the radiation frequency of the generator.[3] The dipoles are made of 2-mm copper wire and are 60 mm long. The emitter, like the x-ray tube, is permanently mounted on the demonstration table. The horizontal axes of rotation of the "crystal" is mounted with the aid of bearings on two vertical posts 6 made of transparent plastic. An arm 7, which carries the receiving horn antenna 3, is secured on a separate bearing behind the sample, on its rotation axis. To observe the scattering at all possible angles, the receiving antenna can be moved together with the arm in a vertical plane along a circle with center on the rotation axis of the sample. The rotation of the receiving antenna 3 can be synchronized with the aid of a pantograph 8 with the rotation of the sample 4 in such a way that rotation of the antenna through an angle θ causes rotation of the

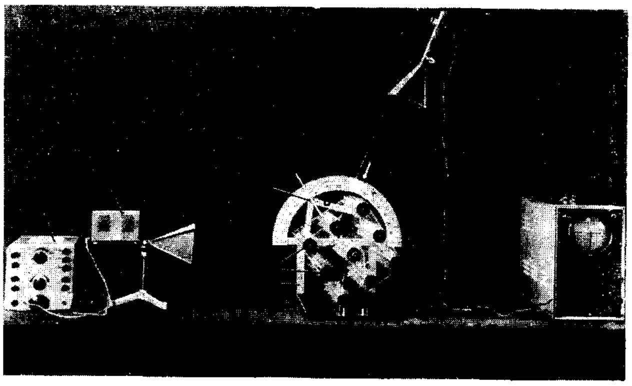


FIG. 1. Setup for the demonstration of x-ray photography of a rotating crystal. 1 – 3-cm wave generator; 2 – power supply; 3 – receiving horn antenna; 4 – crystal model; 5 – "atoms" of crystal model; 6 – posts for securing the "crystal" axis; 7 – arm; 8 – pantograph; 9 – guide; 10 – bar connected to the "crystal"; 11 – scale; 12 – posts for securing the scale.

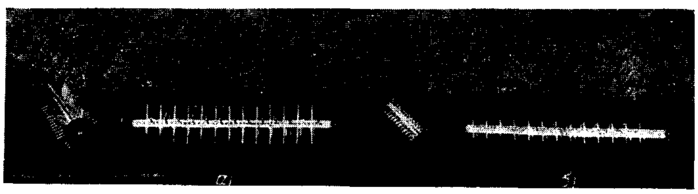
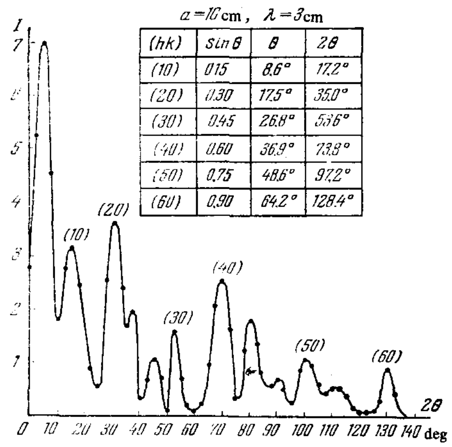


FIG. 2. "Atoms" of the crystal.



$a = 10$ cm, $\lambda = 3$ cm

(hk)	sin θ	θ	2θ
(10)	0.15	8.6°	17.2°
(20)	0.30	17.5°	35.0°
(30)	0.45	26.8°	53.6°
(40)	0.60	36.9°	73.8°
(50)	0.75	48.6°	97.2°
(60)	0.90	64.2°	128.4°

FIG. 3

sample through $\theta/2$. or they can also rotate independently. The double Bragg scattering angle is read on a scale 11, which is mounted on two posts 12.

The dipoles of the "crystal" are located at the sites of a tetragonal lattice with translations a = b = 10 cm and c = 0.5 cm. The rotation axis of the "crystal" is parallel to the translation c. The receiving antenna fixes the position of the interference maxima of the scattering on a null layer line, and therefore the interference index l is always equal to zero.[4] It is impossible to fix the interference maxima of the first layer line, since $c/a \ll 1$.

When the students are being acquainted for the first time with the production of x-ray patterns by the rotating-crystal method, it is preferable from the methodological point of view to regard the proposed crystal model as "two-dimensional" with nine "atoms" located in a vertical plane and forming a rectangular unit cell with a lattice "constant" a = b = 10 cm. To each of the nine "atoms," in a direction perpendicular to the plane, there is set in correspondence a set of 53 copper dipoles (Fig. 2a) mounted on a dielectric rod 300 mm long. The dipoles of each "atom" are rotated relative to one another through 45°. This is done to make the distribution of the scattering amplitude of each "atom" in a plane perpendicular to its axis closer to a radially-symmetrical distribution. All nine dielectric rods with the copper dipoles are secured with the aid of screws to front and rear dielectric plates (see Fig. 1) made of transparent plastic and measuring 240 × 240 xm.

The "crystal" is irradiated with a wave whose electric vector E lies in the vertical plane.

1. The first demonstration consists of observing interference maxima due to the reflection from the crystal planes with indices (10), (20), etc. in accordance with the scheme employed in diffraction meters for receiving antennas moving on a circle with center on the rotation axis of the sample. In this experiment, the rotation of the sample and of the receiving antenna are synchronized. The initial setting of the crystal is shown in Fig. 1. Figure 3 shows the results of a calculation of the scattering angles for the "crystal" with "lattice constant" a = 10 cm and at a receiving radiation wavelength λ = 3 cm. The calculation of the scattering angle was made in accordance with the well known[4] x-ray diffraction formula

$$\sin\theta = \frac{\lambda}{2a}\sqrt{h^2+k^2}, \tag{1}$$

where a is the "lattice constant," λ the wavelength of the employed radiation, and (hk) are the Miller indices of the planes.

The same figure shows an experimental "x-ray pattern," i.e., the dependence of the deflection of the beam on the oscilloscope screen on the angle 2θ as read on the instrument scale. The positions of most interference maxima are in full agreement with the tabulated values of the angles. However, two additional maxima due to extraneous effects, are observed at 45 and 80°.

To observe the interference maximum due to reflection from the diagonal plane with Miller indices (11), the "crystal" is rotated about its axis through an angle 45° relative to the fixed generator and receiver; the rotation of the sample is then again synchronized with that of the receiving antenna. The observed interference maximum from the plane (11) at an angle $2\theta = 25°$ is in full agreement with that calculated in accordance with formula (1), which yields for it the value 24.4°.

2. The setup for the second variant of the demonstration, intended to illustrate photographically the production of x-ray patterns by a rotating crystal, consists of the same elements. However, the demonstrator rotates the receiving antenna and the sample independently of each other. The sample is rotated by a motor having a constant speed of 1 rpm. The dipoles of the "crystal" also form a tetragonal lattice with translations a = b = 3.5 cm and c = 0.5 m. The small "lattice constant"

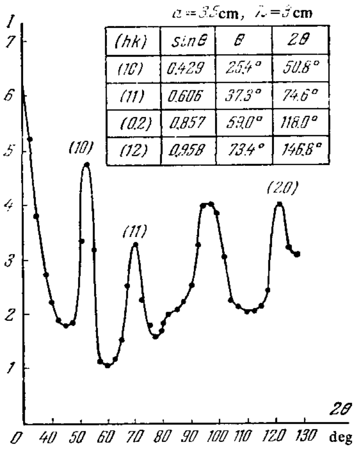


FIG. 4

is obtained by using copper dipoles 3 cm long (Fig. 2b). The use of a sample with a small "lattice constant" makes it possible to obtain a smaller number of interference maxima and to delineate them more distinctly.

In this case the demonstration is made in the following manner. After turning on the centimeter-wave generator, the motor that rotates the sample, and the oscilloscope, the receiving antenna is moved slowly along a circle with center on the sample rotation axis. The oscilloscope screen then displays the short-duration reception pulses, and the receiving-antenna positions at which these reception pulses are maximal are determined. These positions correspond to the positions of the interference maxima.

Figure 4 shows the scattering angles for a "lattice constant" $a = 3.5$ cm and $\lambda = 3$ cm, calculated in accordance with formula (11), and the experimental "x-ray pattern," plotted for the same "lattice constant." The first three maxima can be distinctly separated against the overall background of the scattering of the centimeter waves. The interference maximum at $2\theta = 146.8°$, due to reflection from the (12) plane, was too weak to be distinctly separated. The additional scattering at 95° is due to extraneous effects.

In addition to directly illustrating the methods of obtaining x-ray patterns, the described setup makes it possible to observe the attenuation of the radiation passing through the crystal at the instant of its maximal reflection from the same crystal, and vice versa. To this end, after stopping the "crystal" and the receiver in the position of maximum reflection for any Bragg angle, the receiving antenna is moved with the sample kept fixed in a horizontal position, and the intensity of the transmitted ray at maximum reflection is noted. Then, by rotating the "crystal" somewhat (this disturbs the condition for maximum reflection), an increase in the intensity of the transmitted ray is observed. This can be done most effectively by using two receiving antennas, one for the transmitted ray and the other for the ray reflected at the Bragg angle. Then, as the "crystal" is rotated, the intensities of the transmitted and reflected rays are observed to change in opposite directions.

The "crystals" of the described setups make is possible to vary the "lattice constant" by repositioning eight peripheral "atoms." Then the maximum radiation scattering is observed at other angles. In both setups, it is possible to demonstrate the inverse process, i.e., observation of the interference maxima at Bragg angles, satisfying the condition $90° < 2\theta < 180°$.

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[1] N. A. Kaptsov, Diffraction of Electromagnetic Waves in a Spatial Lattice. Proceedings of Third Congress of Russian Association of Physics in Nizhniĭ Novgorod, 1923.

[2] N. A. Kaptsov, Ann. Physik 69 (4) (1922).

[3] N. M. Shakhmaev, Fizika v shkole (Physics in the School) No. 4, 67 (1960).

[4] G. S. Zhdanov and Ya. S. Umanskiĭ, Rentgenografiya metallov (X-ray Studies of Metals), 1941.

Translated by J. G. Adashko