α is the fraction of the energy transformed into heat, C is the specific heat, ρ is the density of the substance of the inhomogeneity, and ξ is the fraction of the time for the formation of a halo. For example if $\Delta T_{th} \approx 100°K$, $\alpha \approx 1$, $a \approx 10^{-3}$ cm, $\xi\tau_m \approx 10^{-7}$ and ρC is of the order of several joules per 1 cm^3, we find that $I_{th} \approx 1$ MW/cm^2.

Although at lower intensities of the light beam the rate of increase of the halo dimensions is much smaller, the halo may still have a considerable effect in the case of long flashes. Then the halo overlap time is $\tau_m \approx 1/\pi nDL$, where D is the diffusion coefficient of heat or matter from the inhomogeneity. For slow heating of the medium near the inhomogeneity the thermal expansion accompanies the diffusion of heat quasistatically without generating volume waves which could have transported the disturbances or the medium density at a much higher rate.

In the case of the diffusion halo the transmitted intensity is

$$I(L, \tau) = I_0(\tau) \exp\{-n_{av} L\pi(a_0^2 + D\tau)\},$$

i.e., the scattering depth is $l_m(\tau) \approx 1/n\pi(a_0^2 + D\tau)$ and the transmission time is $\tau_m \approx 1/nDL$. For example for $n \approx 10^2$ cm^{-3}, $L \approx 10^4$ cm, $D \approx 0.1$ cm^2/sec (the diffusion coefficient for heat in air is of this order), we find $\tau_m \approx 3$ μsec.

The possible linking of halos does not remove the residual optical inhomogeneity of the medium because of the continuing spatially nonuniform evolution of heat at inhomogeneities and because of edge nonuniformities at halo overlaps.

For short flashes the elimination of the inhomogeneities by vaporization, burning out, or fracture does not remove the scattering centers since the disturbances of the refractive index of the medium (vapors or gases of the substance forming the inhomogeneity, local heating from the interaction events, etc.) still remain and a long time is needed for them to disperse.

These ideas stress the importance of allowing for trace substances and inhomogeneity halos in the problem of the scattering of intense light.

It would be useful to study this effect not only under natural conditions (clouds, fog, dust, smoke) but also under laboratory conditions: in emulsions, colloidal solutions and suspensions in liquids, in gases, as well as in solids with absorbing occlusions. Such systems could be used as cells with rapidly varying scattering properties to limit or modulate intense light beams.

Concluding, the author expresses his gratitude to Professor M. S. Rabinovich and to Corresponding Member of the Academy of Sciences A. M. Prokhorov for their interest in this work and valuable comments.

---

[1] Askar'yan, Prokhorov, Chanturiya, and Shipulo, JETP 44, 2180 (1963), Soviet Phys. JETP **17**, 1463 (1963).

Translated by A. Tybulewicz
135

NEUTRON DIFFRACTION INVESTIGATIONS OF SOLID OXYGEN

R. A. ALIKHANOV

Institute of Physics Problems, Academy of Sciences, U.S.S.R.

Submitted to JETP editor June 19, 1963

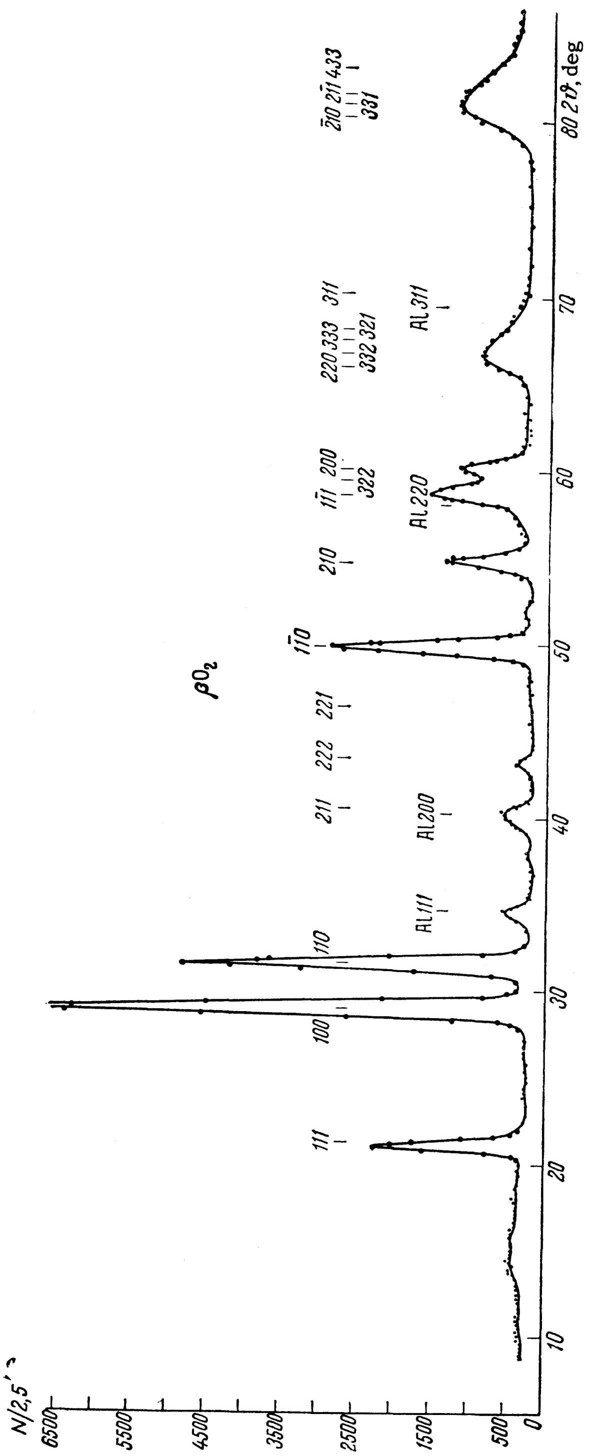
J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 812-814 (September, 1963)

WHEN the temperature is lowered below its melting point (54.39°K) liquid oxygen goes successively through three solid phases, (γ, β, and α) with respective transition temperatures 43.76 and 23.88°K. Measurements of the specific heat and of the susceptibility have disclosed anomalies at these temperatures, pointing to noticeable changes in the properties of solid oxygen in the region of low temperatures[1-3].

The difference in the phases of solid oxygen was investigated by x-ray diffraction numerous times. Patterns of diffraction by solid oxygen, measured at various temperatures, have been published[4-9]. An examination of the crystallographic and magnetic data on the modification of oxygen shows that the phenomena observed in this substance at low temperatures have a complicated and still unclear character, and to difficulties in the experimental investigations by the indicated methods.

In the present investigation, neutron-diffraction studies of solid oxygen were made with an aim at using the capabilities of neutron diffraction to ascertain the crystalline and magnetic properties of oxygen at low temperatures.

The research technique has already been described[10]. An exception is the procedure for working with condensed gases. Its main elements were a cryostat and a system for filling and storing the gas. The cryostat used was, as before[11], a Kapitza hydrogen Dewar[12]. In the new model of the cryostat, however, it is significant that the bath temperature is assumed not only by the appendix but also by the additional radiation screen. The introduction of this screen ensured exact equality of the sample and bath temperatures, unlike the preceding construction which used only a nitrogen screen.



Neutron pattern of solid oxygen obtained at 27°K; ordinates—number of counts in 2.5 minutes, abscissas—scattering angle.

The diffraction of neutrons by the oxygen was measured with the bath filled with liquid neon, hydrogen, and helium. A neutron diffraction pattern obtained at 27°K (T_{Ne}), i.e., of the β phase of oxygen, is shown in the figure.

The position of the diffraction lines is well described by a rhombohedral cell with parameters a = 4.210 and $\alpha = 46°16'$ [9]. The ratio of the measured intensities of the maxima of the reflections is in better agreement with the space group D_{3d}^5 [oxygen atoms with coordinates (uuu) and ($\bar{u}\bar{u}\bar{u}$), where u = 0.055] than Hörl's results (which presented data with visual estimate of the electron diffraction pattern). This applies both to the (110) line, which is too weak in Hörl's data, and to the lines located at larger scattering angles, obtained up to $(\sin\theta)/\lambda \sim 0.5\,\text{Å}^{-1}$.

Comparison of the intensities (111), (100), and (110) with the calculated values, and also with the measurement data of Black et al [13], who published a record of x-ray scattering in the narrow region of small scattering angles $0.1\,\text{Å}^{-1} < (\sin\theta)/\lambda < 0.2\,\text{Å}^{-1}$, shows that the neutron diffraction pattern contains an additional contribution (compared with nuclear) to reflections (111) and (110). The nature of this contribution is apparently magnetic, but it is difficult to interpret it on the basis of a uniaxial antiferromagnet.

Measurements on single-crystal βO_2 and in a beam of polarized neutrons will make it possible to define more precisely the magnetic properties of the β phase.

The present investigations yielded also neutron diffraction patterns at oxygen temperatures 20.4 and 4.2°K. The character of the arrangement of the diffraction peaks and their intensity is duplicated at these temperatures, but differs from that observed in the β phase. This gives grounds for assuming that these neutron patterns belong to the α phase of oxygen. There is no corresponding analog among the hitherto published sets of diffraction lines ascribed to the α phase of oxygen. In all the previous investigations the results apparently pertained to a mixture of the β and α modifications, due to the closeness of the $\beta \rightarrow \alpha$ transition to the temperature of the bath in which the measurements were made. Detailed results and a complete analysis of the properties of α oxygen will be given later. It can be stated presently that the $\beta \rightarrow \alpha$

transition is one that changes the crystal lattice. The appearance of an additional peak in the region of small angles, compared with [13], indicates that α oxygen is antiferromagnetic.

I am deeply grateful to Academician P. L. Kapitza for continuous interest and attention to the work. I thank A. S. Borovik-Romanov and I. E. Dzyaloshinskiĭ for a useful discussion.

---

[1] W. F. Giauque and H. L. Johnston, J. Am. Chem. Soc. **51**, 2300 (1929).

[2] Borovik-Romanov, Orlova, and Strelkov, DAN SSSR **99**, 699 (1954).

[3] Kanda, Haseda, and Otsubo, Physica **20**, 131 (1954).

[4] J. L. McLennan and J. O. Wilhelm, Phil. Mag. 7/3, 383 (1927).

[5] M. Ruhemann, Z. Physik **76**, 368 (1932).

[6] H. H. Mooy, Leiden, Comm. No. 233a (1932).

[7] L. Vegard, Z. Physik **98**, 1 (1935).

[8] W. H. Keesom and K. W. Taconis, Leiden Comm. No. 240d (1936).

[9] E. M. Hörl, Acta Cryst. **15**, 845 (1962).

[10] R. A. Alikhanov, JETP **36**, 1690 (1959), Soviet Phys. JETP **9**, 1204 (1959).

[11] R. A. Alikhanov, JETP **38**, 806 (1960), Soviet Phys. JETP **11**, 585 (1960).

[12] P. Kapitza and P. Cockroft, Nature **129**, 224 (1932).

[13] Black, Bolz, Brooks, Mauer, and Peiser, J. Res. NBS **61**, 367 (1958).

Translated by J. G. Adashko
136

IONIZATION OF POSITIVE IONS BY ELECTRONS

S. E. KUPRIYANOV and Z. Z. LATYPOV

L. Ya. Karpov Physico-chemical Institute

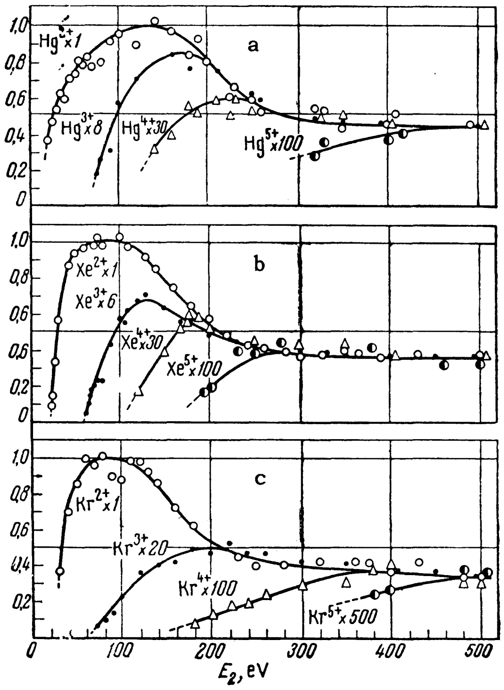
Submitted to JETP editor May 31, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 815-816 (September, 1963)

In connection with phenomena in plasma, it is important at present to study the excitation and ionization of ions in collisions with electrons. These processes have been theoretically treated in several papers, but there is merely one investigation[1] devoted to an experimental study of the ionization of He^+ ions by electrons.

We studied experimentally the ionization of singly-charged ions Hg^+, Xe^+, Kr^+, Ar^+, Ne^+ and the doubly charged ions Hg^{2+}, Xe^{2+}, Kr^{2+}. The method of crossing electron and ion beams was used. The investigation was made with a double mass spectrometer[2] in which the collision chamber, located between two magnetic mass analyzers, was replaced by an electron gun. The electron current was varied from 1 to 20 mA, and the electron energy E_2 was varied from 10 to 500 eV. The ions were accelerated to 2800 eV. The energy E_1 of the electrons ionizing the gas in the ion source was varied from 10 to 180 eV. The working pressure in the ion source was approximately 5×10^{-5} mm Hg and in all other parts of the mass spectrometer it was $(1-3) \times 10^{-6}$ mm Hg. The background pressure was 5×10^{-8}–3×10^{-7} mm Hg.

The figure shows the relative cross sections of the different degrees of ionization of Hg^+, Xe^+, Kr^+, as a function on the electron energy E_2.1) It can be seen that they are similar to the ionization curves of neutral atoms[3,4]. As follows from the figure, the yield curves for differently charged ions become approximately the same for energies $E_2 \geq 3E_i$, where E_i is the potential for the appearance of the next ion. The curves for the yield of Xe^{2+} and Kr^{2+} are quite similar, but differ from the



Relative cross sections for the ionization of ions as functions of energy E_2 of the electrons: a – ionization of Hg^+ ($E_1 = 160$ eV), b – ionization of Xe^+ ($E_1 = 160$ eV), c – ionization Kr^+ ($E_1 = 90$ eV). The numbers on the curves denote the coefficients by which the corresponding cross sections have been increased. Unity corresponds to the cross section for the production of doubly-charged ions at the maximum.