# On the continuous spectra emitted by particles knocked out by ion beams from metal targets

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The continuous spectrum emitted by particles ejected by the ions $He^+$, $Ne^+$, and $Ar^+$ from 42 different metal targets is investigated. It is established that a continuous spectrum is emitted only by particles ejected from targets whose atoms have unfilled *nd* shells (transition metals) or unfilled *4f* shells (rare-earth metals). The intensity distribution in the continuous spectrum emitted by particles ejected from transition-metal targets almost does not depend on the nature of the metal. In the case of the rare-earth metals this distribution varies regularly as the *4f* shell of the atoms of the metal is filled. An analysis of the results of the work and a comparison of them with the data available in the literature lead to the conclusion that in some cases (Mo) different sections of the continuous spectrum are emitted by different types of particles. In the general case the investigated continuous spectrum may be emitted either by the target-material atoms excited to a collective level, or by excited clusters of the metal atoms.

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## INTRODUCTION

The emission of a continuous spectrum pertains to a number of phenomena often encountered in nature. A continuous spectrum is emitted by heated bodies; by solids excited by electron or ion bombardment; during the deceleration of electrons or the crossing by them of a vacuum-solid boundary; in the course of recombination processes in plasmas and flames. Widely known are the continuous spectra emitted by diatomic molecules during electron transitions between states to which correspond discrete and continuous energy levels.[1] Continuous spectra can also be emitted during electron transitions in multi-atomic molecules. However, as has been asserted by Herzberg,[2] such spectra have not been experimentally observed. This is connected with the fact that polyatomic molecules break up in plasma sources of light. Quite specific polyatomic-molecule-excitation conditions are necessary for the observation of the continuous spectrum emitted by such molecules.

In the present paper we present experimental results obtained in an investigation of the continuous spectrum emitted by particles excited in the process of their ejection by an ion beam from a number of metallic targets. The process of excitation of particles ejected by ion impact from solids differs from the process of excitation of particles of the gaseous phase by an ion beam in that in the first case the excited particle 1) was part of a strongly interacting group of particles, 2) as it flew away, it crossed the solid-vacuum boundary, and 3) prior to the excitation process it had an effective positive charge, but in the excited state it turned out to be neutral.[1)] As to the nature of the ejected excited particles, they can first and foremost be atoms of the material of the target itself, since atomic lines of the target material are observed in the spectrum of the luminous halo. In principle, the ejection from the target of excited diatomic molecules of the metal, as well as of excited clusters,[2)] is possible. When the target is located in an insufficiently high vacuum the ejection by ions of excited diatomic and multiatomic molecules of surface chemical compounds of the particles of the metal with particles of the residual gases of the vacuum is possible.[3)]

In view of the foregoing, it caused no special surprise when for the first time during the bombardment of a tungsten target by $Ar^+$ ions[5,6] a continuous spectrum was observed in the radiation of the halo. The observed continuous spectrum could be explained by the emission of photons during the radiative decay of the excited states of some molecules ejected by the ion beam from the target.[6] However, a further investigation of the continuous spectrum in question[7] led to the establishment of a number of factors that are not in accord with the proposed hypothesis. This phenomenon turned out to be quite unusual, and its nature has not been definitely established right up to the present time. One of the possible hypotheses explaining the origin of this new type of continuous spectrum is discussed in the present paper.

## APPARATUS AND EXPERIMENTAL CONDITIONS

In the present work we used the experimental setup described in Ref. 8. The radiation emitted by particles knocked out from a number of metallic targets by beams of $He^+$, $Ne^+$, and $Ar^+$ ions of energy 30 keV and beam-current density 200 $\mu A/cm^2$ was analyzed with the aid of an ISP-51 spectrograph in the wavelength range 4000–7000 Å. The radiation spectrum was photographed on a KN-4S film sensitized in the long-wavelength part of the indicated wavelength range.

Bearing in mind that there can arise during the bombardment of a metal by an ion beam radiation emitted by the target surface, we had to secure an experimental geometry in which the radiation from the target surface could not reach the entrance slit of the spectrograph. The indicated aim was achieved by aligning the axis of the spectrograph in a direction perpendicular to the plane formed by the axis of the bombarding beam and the normal to the target surface (see Fig. 1 in Ref. 9). To clean the targets, in particular, to remove alkali-metal and carbon impurities from them, some of the

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targets (W, Mo) were annealed for a long time before the beginning of the experiment at a temperature of 1800 K in a high vacuum and in an atmosphere of rarefied oxygen.

The experimental setup was evacuated by oil-diffusion pumps. The decomposition products of the oil of the diffusion pumps were frozen out with the aid of traps located above the pumps and near the target, and filled with liquid nitrogen. The residual-gas pressure in the target chamber was equal to $1 \times 10^{-6}$ Torr. We did not observe the formation of a carbon film on the surface of a target during its bombardment by an ion beam.

## THE EXPERIMENTAL RESULTS AND THEIR DISCUSSION

In the course of the work we investigated the emission spectra of excited particles ejected from targets of 42 elements of the Mendeleev periodic table (see Table I). As can be seen from the table, continuous spectra were emitted by particles ejected from targets whose atoms have an unfilled inner shell. Into this group enter the transition metals (atoms with an unfilled *d* shell) and the rare-earth metals (atoms with an unfilled 4*f* shell). The only exception to this rule is palladium, whose atoms have an unfilled 4*d* shell, but the intensity of the continuous spectrum in this case is very low.

The continuous spectrum emitted by ejected particles has been studied by a number of other investigators[10–19] (it should be emphasized that not in one of the indicated works were so large a number of targets investigated; in particular, nobody has investigated rare-earth-metal targets). The exceptions to the rule established in the present work were not observed. In all the cases the continuous spectrum was emitted by particles ejected from transition metals.

The intensity distribution in the continuous spectrum is one of the most important characteristics of the spectrum. In order to establish the nature of this distribution, all the obtained photographs of the continuous spectrum were photometrically scanned and, thus, the dependences $S(\lambda)$ ($S$ is the blackening of the film and $\lambda$ is the wave-length) were obtained. In some cases, we obtained by means of the usual procedure for converting the blackening on a film into the intensity of the radiation that produced it the distribution curves for the relative intensity $I(\lambda)$ in the continuous spectra of the rare-earth metals.

Table I.

| Element | Electron configuration | Continuous spectrum | Element | Electron configuration | Continuous spectrum |
|---|---|---|---|---|---|
| $^{4}$Be | [He] $2s^2$ | absent | $^{50}$Sn | [Kr] $4d^{10}5s^25p^2$ | absent |
| $^{6}$C | [He] $2s^22p^2$ | » | $^{57}$La | [Xe] $5d^16s^2$ | present |
| $^{12}$Mg | [Ne] $3s^2$ | » | $^{58}$Ce | [Xe] $4f^26s^2$ | » |
| $^{13}$Al | [Ne] $3s^23p^1$ | » | $^{59}$Pr | [Xe] $4f^36s^2$ | » |
| $^{14}$Si | [Ne] $3s^23p^2$ | » | $^{60}$Nd | [Xe] $4f^46s^2$ | » |
| $^{20}$Ca | [Ar] $4s^2$ | » | $^{62}$Sm | [Xe] $4f^66s^2$ | » |
| $^{22}$Ti | [Ar] $3d^24s^2$ | present | $^{63}$Eu | [Xe] $4f^76s^2$ | » |
| $^{23}$V | [Ar] $3d^34s^2$ | » | $^{64}$Gd | [Xe] $4f^75d^16s^2$ | » |
| $^{24}$Cr | [Ar] $3d^54s^1$ | » | $^{65}$Tb | [Xe] $4f^85d^16s^2$ | » |
| $^{26}$Fe | [Ar] $3d^64s^2$ | » | $^{66}$Dy | [Xe] $4f^{10}-6s^2$ | » |
| $^{28}$Ni | [Ar] $3d^84s^3$ | » | $^{67}$Ho | [Xe] $4f^{11}-6s^2$ | » |
| $^{29}$Cu | [Ar] $3d^{10}4s^1$ | absent | $^{68}$Er | [Xe] $4f^{12}-6s^2$ | » |
| $^{30}$Zn | [Ar] $3d^{10}4s^2$ | » | $^{69}$Tm | [Xe] $4f^{13}-6s^2$ | » |
| $^{39}$Y | [Kr] $4d^15s^2$ | present but weak | $^{70}$Yb | [Xe] $4f^{14}-6s^2$ | absent |
| $^{40}$Zr | [Kr] $4d^25s^2$ | present | $^{71}$Lu | [Xe] $4f^{14}5d^16s^2$ | present |
| $^{41}$Nb | [Kr] $4d^45s^1$ | » | $^{73}$Ta | [Xe] $4f^{14}5d^36s^2$ | » |
| $^{42}$Mo | [Kr] $4d^55s^1$ | » | $^{74}$W | [Xe] $4f^{14}5d^46s^2$ | » |
| $^{46}$Pd | [Kr] $4d^{10}$ | present but weak | $^{75}$Re | [Xe] $4f^{14}5d^56s^2$ | » |
| $^{47}$Ag | [Kr] $4d^{10}5s^1$ | absent | $^{78}$Pt | [Xe] $4f^{14}5d^96s^1$ | » |
| $^{48}$Cd | [Kr] $4d^{10}5s^2$ | » | $^{79}$Au | [Xe] $4f^{14}5d^{10}6s^1$ | absent |
| $^{49}$In | [Kr] $4d^{10}5s^25p^1$ | » | $^{82}$Pb | [Xe] $4f^{14}5d^{10}6s^16p^2$ | » |

In Fig. 1 we show the $S(\lambda)$ curves for a number of transition metals that emit a continuous spectrum when bombarded by Ar$^+$ ions. (The shape of the $S(\lambda)$ curve for the continuous spectrum obtained in the bombardment of one and the same target by He$^+$, Ne$^+$, and Ar$^+$ ions does not depend on the nature of the bombarding ions.) The corresponding curves for the rest of the investigated transition metals do not differ in shape from the curves shown. A surprising property of the $S(\lambda)$ curves for the transition metals is the fact that their shape changes only to an insignificant degree in going from one metal to another. The locations of the principal peaks of the spectrum remain the same for all the investigated metals; only the radiation intensities at these peaks change slightly. The above-noted regularity in the behavior of the intensity distribution in the continuous spectra of the transition metals seemed so unusual that it was suggested that this continuous spectrum was emitted by particles of some kind of impurities present in all the investigated targets. For the purpose of verifying this hypothesis, the tungsten and molybdenum targets were subjected to prolonged annealing at a temperature of 1800 *K* in a high vacuum and in an atmosphere of rarefied oxygen. Such a treatment significantly reduces the quantity of impurities in metals, in particular, carbon and alkali-metal impurities.[20,21] But the intensity distribution in the continuous spectra of tungsten and molybdenum subjected to the indicated treatment did not change in comparison with the original distribution.

In Ref. 13 a comparison is also carried out of the intensity distributions in the spectra of a number of transition metals (Y, Ti, Zr, Nb, Ta, and Mo) in the wavelength range 2350 – 5200 Å. The intensity distributions in the spectra of five of them turned out to be identical in their main features, and only in the spectrum of molybdenum were very intense bands that were not in the spectra of the remaining investigated metals observed in the 2960- and 3450-Å regions. The cause of the divergence of the spectrum of molybdenum from the spectra of the remaining metals will be considered below.

The intensity distribution in the continuous spectrum of the rare-earth metals (in contrast to the distribution

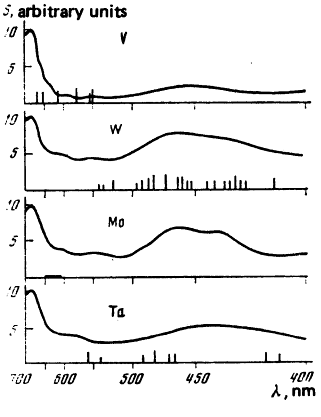

FIG. 1. Intensity distribution of the continuous spectrum of the transition metals as a function of the wavelength.

for the transition metals) turns out to be dependent on the nature of the metal. As can be seen from Fig. 2, in which we show the intensity distribution curves for the continuous spectra of the rare-earth metals from lanthanum to lutecium (here we do not present the $I(\lambda)$ curves for ytterbium, since the atom of this metal has a filled $4f$ shell and does not emit a continuous spectrum), definite changes occur in the shape of the curves shown as the $4f$ shell is filled. In the case of lanthanum, the first of the investigated group of metals, a strongly pronounced intensity peak, which is not present in the spectra of the transition metals, and which disappears in the spectra of all the rare-earth metals following lanthanum, is observable in the spectrum at the wavelength $\lambda = 4450$ Å. On the other hand, the spectrum of lanthanum does not contain the intensity peak labeled by the letter $A$, which is observed in the spectra of all the remaining rare-earth metals. It is possible that this distinctive feature of the spectrum of lanthanum is connected with the fact that the configuration of the electron shell of its atom is different from the configuration in the atoms of the transition metals and in the atoms of the rare-earth metals following it. Indeed, in the case of lanthanum one electron appears in the $5d$ shell when the $4f$ shell is completely devoid of electrons, whereas in the atoms of the transition metals the filling of the $d$ shells occurs either in the absence of a $4f$ shell (Zr, Nb, Mo), or after the $4f$ shell has been completely filled (Ta, W, Re, Pt). The rare-earth elements following lanthanum differ from it in that the $4f$ shell in them is filled gradually.

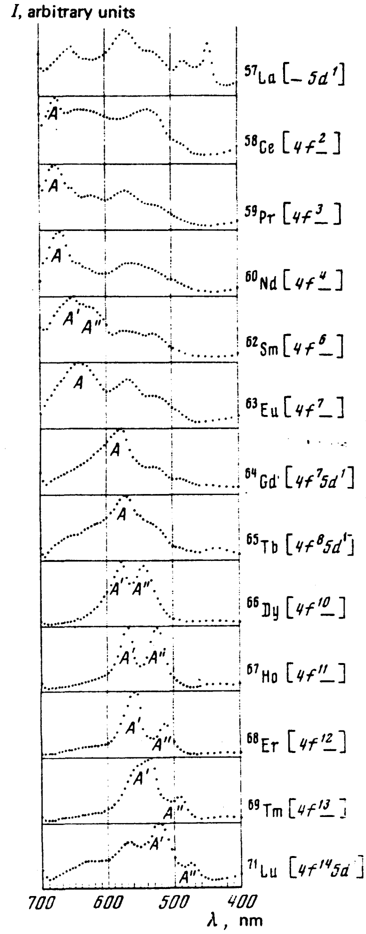

FIG. 2. Dependence of the intensity of the continuous spectrum of the rare-earth metals on wavelength.

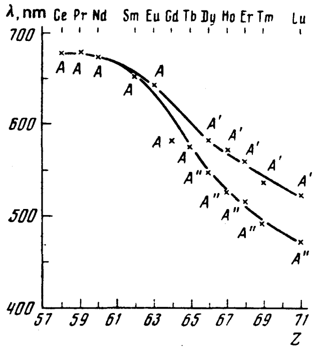

FIG. 3. Dependence of the positions of the principal peaks in the intensity distribution of the continuous spectrum of the rare-earth metals on the charge number of the atoms.

The following law can be observed to exist in the intensity distribution of the continuous spectrum of the rare-earth metals following lanthanum, from cerium to lutecium. The long-wavelength intensity peak $A$ (in the case of cesium $\lambda = 6750$ Å) shifts gradually toward the short-wavelength part of the spectrum as the $4f$ shell is filled. Beginning with dysprosium, this peak splits up into the peaks $A'$ and $A''$. Figure 3 shows the regular displacement of the indicated peaks ($A, A', A''$) toward the short-wavelength region of the spectrum as the charge number, $Z$, of the atoms of the investigated rare-earth metals increases. The positions of the other peaks ($\lambda = 5700$ Å and $\lambda = 5250$ Å) that are observed in the continuous spectra of the rare-earth metals do not change as the $4f$ shell of the atoms of these metals is filled.

Thus, the above-presented results of the study of the continuous spectra of the large group of metals allow us to draw the following conclusions.

1. A continuous spectrum is emitted only by particles ejected from metals whose atoms have an unfilled inner shell.

2. The intensity distribution in the continuous spectra of the transition metals almost does not depend on the nature of the metal.

3. The intensity distribution in the continuous spectra of the rare-earth metals changes regularly as the $4f$ shell of the atoms of these metals is filled.

From the above-drawn conclusions thus follows the result that there exists a relation between the capacity of particles ejected from a metal to emit a continuous spectrum and the properties of this spectrum, on the one hand, and the configuration of the electron shell of the atom of the metal, on the other.

The relative photon yield for the continuous spectrum per incident ion is not the same for different metals. In the group of transition metals the larger the principal quantum number of the unfilled $d$ shell is, the greater is this yield. Within the limits of one row of the periodic table, the greatest photon yield is given by metals whose atoms have four of five electrons in the $d$ shell. In the group of the rare-earth metals, the relative photon yield is very high: it is, in order of magnitude, the same as for tungsten, which has the greatest yield in the group of transition metals.[4] The photon yield in the group of rare-earth metals does not noticeably depend on the extent to which the 4*f* shell has been filled.

For the purpose of ascertaining the sign of the charge of the particles emitting the continuous spectrum, a potential of ± 2 kV with respect to the earth was applied to the target. The application of the potential to the target did not lead to a change in the intensity distribution or in the overall intensity of the continuous spectrum. A similar result was obtained by the authors of Refs. 12 and 13. From these results follows the conclusion that a continuous spectrum is emitted by neutral particles.

In conclusion of the discussion of the experimental results, we should further mention the following.

1. The intensity of the continuous spectrum emitted during the ion bombardment of tungsten and molybdenum targets does not change when the targets are heated up to 500 K.

2. The continuous spectrum disappears when oxygen or argon is admitted into the target chamber to produce a pressure of $10^{-3}$ Torr.

3. The yield of continuous-spectrum photons increases with increase in the mass of the bombarding ion. (The same conclusion was arrived at by the authors of Refs. 15 and 19.)

On the basis of the experimental results of the present work, as well as of the experimental results of other authors, we can express some opinions about the nature of the ejected particles emitting the continuous spectrum.

The origin of the continuous spectrum could be most simply explained as the emission of excited diatomic molecules of the metal in going into a lower electronic state with unquantized energy. Such was the original conjecture of the authors of the present paper[6] and, later, the authors of Ref. 13 took the same view. However, an in-depth study of the continuous spectrum in question compelled us to abandon this hypothesis, since one of the main results, namely, the independence of the intensity distribution in the spectrum of the transition metals of the nature of the metal, is clearly at variance with this hypothesis. Indeed, if the continuous spectrum were emitted by an excited diatomic molecule of the metal, then we should have observed an appreciable influence of the nature of the molecule (i.e., of the nature of the metal) on the intensity distribution in the spectrum emitted by it.

Considering that the majority of the works devoted to the study of the continuous spectrum were carried out under conditions of an insufficiently low partial pressure of oxygen in the target chamber, owing to which the target surface was covered with molecules of surface oxides of the metal and, in the case of highly oxidizable metals, with islets or a continuous film of the volume oxide,[22] it might have been inferred that the continuous spectrum in question is emitted by excited diatomic molecules of the oxides of the metal. This hypothesis in its most precise form was put forward by the authors of Ref. 18 on the basis of experiments in which the effect of the oxygen partial pressure on the intensity of the continuous spectrum of molybdenum was studied. Against this hypothesis are the following strong objections.

The band spectra of some diatomic molecules of metal oxides have been studied, and are tabulated in Pears and Gaydon's monograph.[23] In Fig. 1 we have indicated the wavelengths, taken from this monograph, of the edges of the bands of some diatomic molecules of metal oxides. As can be seen from this figure, the intensity distribution of the continuous spectrum does not exhibit any distinctive features in its behavior in the region of the band edges. On the other hand, the emission spectra of particles ejected from the surfaces of such metals as Be, Mg, Al, Ca, and Cu contain no continuous radiation, but contain the emission bands of the diatomic molecules of the oxides of these metals.[22, 24-26] Furthermore, the wavelengths of the edges of these bands and the relative intensity distribution for these wavelengths have values close to the values given in Pears and Gaydon's monograph.[23] These factors compel us to reject the hypothesis that the continuous spectrum is emitted by diatomic molecules of oxides of the metal.

As to the effect of the partial oxygen pressure on the intensity of the continuous spectrum of molybdenum, an effect which has been observed not only by the authors of Ref. 18, but also by the authors of other works,[12, 13, 15, 19] the following can be said about it.

1. This effect is not universal. In the work published in Ref. 16, in which the emission near the surface of a tantalum target was investigated, the intensity of the continuous spectrum not only did not decrease, but even increased slightly when the partial oxygen pressure was lowered.

2. In the main, the effect whereby the intensity of the continuous spectrum decreases when the partial oxygen pressure is lowered has been studied on the spectral bands of molybdenum that are found in the 2960- and 3450-Å regions, but are absent in the spectra of the rest of the transition metals (see above). Only in one investigation, namely, the one published in Ref. 18, was the disappearance of the remaining part of the continuous spectrum of molybdenum observed when the partial oxygen pressure was reduced below $2 \times 10^{-9}$ Torr. The effect whereby the bands in the continuous spectrum of molybdenum in the 2960- and 3450-Å regions disappear at a low partial oxygen pressure can be explained on the basis of the assumption that these bands are emitted by excited molecules of molybdenum oxides ejected from the target surface. As to the disappearance of the remaining part of the continuous spectrum of molybdenum, as well as of the continous spectra of tungsten and niobium,[18] this result may be due to a completely different cause not connected with the ejection of excited multiatomic molecules of the oxides of the indicated metals. The thing is that absorp-

tion of oxygen on the surface of the metal may lead to a decrease in the probability for a nonradiative excitation transfer to the metal from a particle capable of emitting the continuous spectrum and, thereby, to an increase in the intensity of the continous spectrum. An effect that is to a certain extent similar to the indicated effect is observed in the case of the emission of spectral lines by knocked-out excited metal atoms upon the appearance on the target surface of a bulk oxide of the metal (see Refs. 8, 22, and 24).

The above-performed analysis of the experimental data leads to the result that excited diatomic molecules of the metal itself or of its oxide cannot be the emitters of the continuous spectrum in question. As to excited multiatomic molecules of oxides, their radiation can to some extent explain only that part of the continuous spectrum of molybdenum which is in the region close to the ultraviolet region. Thus, there remain only two types of excited particles that can be responsible for the emission of the continuous spectrum—atoms and clusters.

In principle, clusters ejected from a metal target can have a high temperature and can emit a thermal continuous spectrum. Such a possibility is considered in Ref. 11, but the calculation carried out by the authors of this work shows that the extent of the observed continuous spectrum is greater by two orders of magnitude than the computed quantity. The authors of Ref. 27 have postulated a nonthermal emission by the clusters. This postulated is based on Refs. 28-32, in which the energy spectrum of the electrons in the clusters of a number of metals is computed. These calculations show that the energy spectrum of the clusters is yet to be molded, i.e., differs from the energy spectrum for the bulk metal. In view of this, a cluster may, on being ejected from the metal, turn out to be excited as a result of the formation of holes in the bottom band of the energy spectrum and the population by electrons of the levels in its upper unfilled band. Interband electron transitions in clusters that are in the indicated excited state will lead to the emission of radiation with a nearly continuous spectrum. The possibility that the indicated excitation mechanism is realized only in those clusters which are composed of atoms with unfilled $d$ or $f$ shells is not excluded, which agrees with one of the principal results of the present work.

Nevertheless, some objections can be advanced against the cluster hypothesis. According to the data obtained in the work published in Ref. 3, in which the sputtering of tungsten by Xe$^+$ ions was investigated, the overwhelming majority of the cluster ions $W_n^+$ $(n = 2 - 12)$ have a low kinetic energy (of the order of 20 eV), whereas the atomic ions $W^+$ have a wide energy spectrum (see Fig. 4 in Ref. 3). Furthermore, the enlargement of the cluster by each subsequent atom decreases the total number of these clusters by an order of magnitude. If we assume that there exists a direct connection between the relative numbers of ejected ionic and neutral clusters, then a low intensity of the spectrum emitted by the clusters was to be expected. Nevertheless, it follows from the data of a number of investigations that the intensity of the continuous spectrum and its extent as we move away from the target surface exceed, in a number of cases, the intensity and extent of the atomic emissions. If we relate this circumstance with the high probability for the transitions leading to the emission of the continuous spectrum, then the lifetime of the corresponding excited state should be significantly shorter than that of the excited levels of the atoms. However, according to estimates made in Refs. 9 and 12, the lifetime of the excited state of the particles emitting the continuous spectrum is of the same order of magnitude as, or even longer than, the lifetime of the excited states of the atoms.

If we proceed from the assumption that the continuous spectrum is emitted by excited atoms ejected from the target, then, of course, there can be no question of the excitation of the atoms to single-particle excitation levels, since in that case only a line spectrum can be emitted (it is indeed observed along with the continuous spectrum). In view of this, the authors of the present paper have put forward[7] a hypothesis that explains the emission of the continuous spectrum as due to the radiative decay of ejected atoms excited to a collective-excitation level (or such levels).5)

Recently, Bloch's idea [33] that the collective excitation of the electron shell of an atom is possible has been attracting more and more attention. This circumstance is connected with the fact that at last phenomena have been discovered which cannot, apparently, be explained without the use of the concepts of collective effects in the electron shells of atoms. Among these are: 1) the discovery of a broad photoabsorption band of barium vapor[34]; 2) the appearance of a continuum in the photoelectron spectrum of xenon.[35] These phenomena, which cannot be explained on the basis of the conventional single-particle excitation model for atoms, have been satisfactorily explained by taking account of the collective effects in photon absorption by atoms.[36, 37]

The discussion carried out above leads to the result that the available experimental material does not enable us to express a sufficiently well-founded opinion about the nature of the continuous spectrum under consideration. The primary problem, whose solution will clear the way for further theoretical and experimental investigations of this complex problem, is the establishment of the nature of the particles that emit the continuous spectrum. If follows from the contents of the present paper that such particles can only be either atoms ejected from the target material, or clusters of these atoms. It is possible to propose an experiment that will help determine which of the indicated possibilities is in fact realized. The scheme of this experiment consists in the following. To a tungsten or molybdenum target (tungsten and molybdenum give the most intense continuous spectra) located in an ultrahigh vaccuum and properly cleansed of surface impurities is applied a negative potential, in order to slow down the secondary positive ions ejected from it. The flux of neutral particles ejected from the target is ionized by electrons. The ions thus produced are accelerated and shaped into a beam by an ion-optical system. The beam is then guided into a mass spectrometer, and the ions of fixed mass that are separated out by the analyzer get to the collector of the spectrometer. On the other hand, with the aid of an optical spectrometer photons of given energy are separated out from the continuous spectrum in question and directed to the collector of this spectrometer. The collectors of the two spectrometers are incorporated in a coincidence scheme, and the particle (atom or cluster), reaching the collector of the mass spectrometer, with whose mass the continuous-spectrum emission events correlate is determined.

1) As experiments have shown, the continuous spectrum investigated in the present work is emitted by neutral particles (see below).

2) The ejection of secondary cluster ions has been observed by many investigators (see, for example, Ref. 3).

3) The ejection of secondary molecular ions of this type is a well-known phenomenon.[4]

4) Under the above-indicated experimental conditions, the density of the photograph of the continuous spectrum of tungsten and the rare-earth metals turns out to be sufficient for photometric scanning in the case of an exposure time of the order of several minutes.

5) This hypothesis does not contradict the fact that the emission of a continuous spectrum was not observed during the passage of a beam of Mo$^+$ ions through a gas.[12] It is quite possible that the probability for collective excitation of the electron shell of an atom will be small under the conditions of the experiment described in Ref. 12, but substantial during the ejection of molybdenum atoms from the metallic target (see the Introduction).

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