NOBLE GASES AS OPTICAL TRACERS OF GAS AND ELECTRON FLUXES IN POLAR IONOSPHERE

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Optical effects occurred in the polar ionosphere due to injection of noble gases into it are considered. An analysis is performed using the injection of the Xe atoms as an example. The estimates show that when pulverizing the Xe *atoms at altitudes of* 90–800 km *the surface facilities can record the pulse of the* XeO *radiation and the line quenching of OI. Such tracers enable one to obtain the further insight into the physical processes in polar ionosphere.*

Active experiments in the Earth–orbital space allow investigators to obtain the qualitatively new information on the physical processes occurred in the Earth ionosphere, in particular, to probed deeper into the nature of polar auroras.[1] One of the principal problems of the polar aurora physics is the study of the depth of penetration of the electron flows into the Earth atmosphere and the position of the lower boundary of polar auroras.

The recent data obtained with the help of the surface spatially–separated photometers show that the lower boundary of polar auroras can drop down to the altitudes of 60—70 km, that is essentially different from the earlier adopted values of 100–110 km. It is of importance to determine the altitude profile of the excited atom concentration everywhere within the layer including the lower boundary, where the effects of quenching already manifest themselves. It is of intersect to predict the feasibility of creating an artificial gaseous optical tracer to investigate the polar ionosphere, in particular, to obtain the spatial distribution of excited atoms.

The present paper concerns the optical effects occurred in the polar ionosphere in the case of injection of the noble gas atoms and the feasibility to use them as tracers. Noble gases are well studied from the point of view of their interaction with the electron flows as well as their behavior during atom – atom reactions. Since they are natural constituents of the atmosphere, the noble gases are harmless from the standpoint of the ecological consequences of the experiments being made under natural conditions.

As is well known, the significant contribution into the intensity and spectrum of polar auroras is made by the radiation of the atomic oxygen at the wavelengths $\lambda = 5577$ (the transition $^1S_0 \to {}^3D_0$), 6300 ($^1D_2 \to {}^3P_2$), and 6364 Å ($^1D_2 \to {}^3P_1$). Let us remind that the states $^1S_0$ and $^1D_2$ are metastable, i.e., the radiative lifetime of the first one is approximately equal to 0.7 s, whereas for the second one the corresponding value exceeds 100 s. The high brightness of the forbidden lines of OI in polar auroras is conditioned by the considerable physical thickness of the emitting layer, namely, up to 200 km, and the dissociative character of the excitation of these states of the oxygen atom, which attenuates the radiation absorption and quenching at the lower boundary of the emitting layer to a great extent. Figure 1 shows the terms and transitions in the spectrum of *OI*.

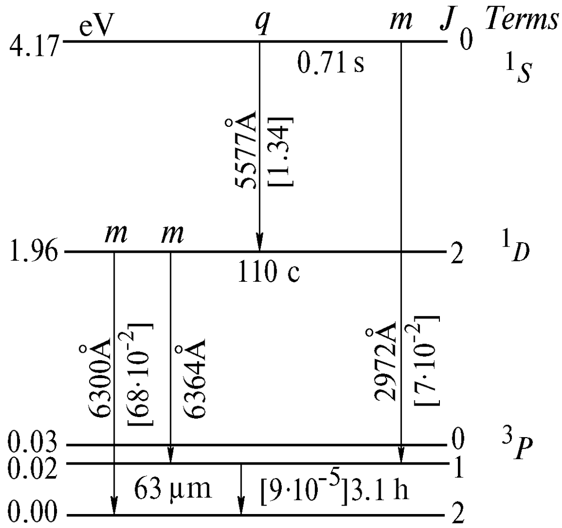

FIG. 1. The ground configuration $1S^2\ 2S^2\ 2P^4$ *of the atomic oxygen OI, the terms and level splittings are shown.*

It is recently established that the radiative properties of the oxygen atoms change essentially in their mixture with noble gases, for example, with Xe (see Refs. 2–4) due to formation of eximer molecules of the type XeO. Thus, it has been found out that the optical transition probability in the XeO molecule corresponding to the atomic line λ = 5577 Å, is 10^5–10^6 times greater than the probability of such transitions in the isolated oxygen atom at the same wavelength.[5–8] The mechanism of the emission is illustrated in Fig. 2.

The radiation of mixture Xe + O is characterized by the considerable shift of the XeO wavelength relative to the transition $^1S_0 \to {}^1D_2$ of the OI atom and the presence of quenching effect at the atomic transitions $^1D_2 \to {}^3P_j$. The latter appears due to the intersection of the potential curve of the $1^1\Sigma^+$ state with the repulsive curve of the XeO ground state.

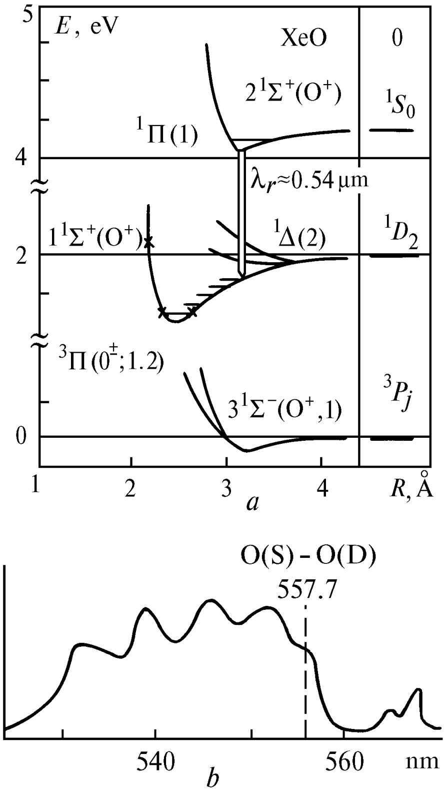

FIG. 2. Potential curves of lower electronic states of the XeO *molecule (a) and luminescence spectrum of* XeO *(b).*

Thus, if the energy, proportional to the density of the excited states $^1S_0$ was stored in these states in some regions of the polar aurora, the addition of Xe leads to its release as a pulse of radiation in the band of XeO with λ = 530–560 nm. The energy stored in the same volume in states $^1D_2$ is released as a kinetic energy of atomic particles, that causes the pulse attenuation of the OI radiation at λ= 6300 and 6364 Å. These signals can be used to construct the spatial profiles of the OI excited states.

Let us consider the conditions under which the above mentioned effect can be observed in the polar ionosphere. The threshold concentration of XeO can be evaluated from the equality of the probabilities of the spontaneous radiation A_{sp} and that of the collision–induced radiation

$$A_{sp} = K_1[\mathrm{Xe}]_{thr},$$

where K_1 is the rate constant of the collisions which induce the radiation, $[\mathrm{Xe}]_{thr}$ is the threshold density of the Xe atoms. The value K_1 equals $2.7\cdot10^{-15}$ cm^{-3} (see Ref. 8), hence, $[\mathrm{Xe}]_{thr} \cong 3\cdot10^{14}$ cm^{-3}. Since A_{sp} at λ = 6300 Å is two orders of magnitude smaller than A_{sp} at λ = 5577 Å, then the threshold Xe concentration enough to quench the red lines is equal ~ 10^{12} cm^{-3}. For comparison, the generalized data on the oxygen atoms density in the emitting layer at altitudes 80–800 km borrowed from Ref. 10 are given in Table I. As can be seen from the table, in order to observe the effects described above, the Xe atoms density should be 1–3 orders of magnitude greater than oxygen density.

TABLE I.

H, km	86	90	100	150	200
[O], cm^{-3}	$8.6\cdot10^{10}$	$2.4\cdot10^{11}$	$4.3\cdot10^{11}$	$1.8\cdot10^{10}$	$4.1\cdot10^{9}$
H, km	250	300	400	500	750
[O], cm^{-3}	$1.4\cdot0^{9}$	$5.4\cdot10^{8}$	$9.6\cdot10^{7}$	$1.8\cdot10^{7}$	$3.7\cdot10^{5}$

Let us make estimates of the pulse intensity of the XeO glow under typical conditions taking place in the upper atmosphere of the high–latitude zone. Assume that the tank filled by Xe is in the geophysical rocket, the speed of which is 10^5 cm/s. When Xe is injected in the direction opposite to the rocket motion, the extension of the Xe region at the initial stage is predominantly determined by the gas dynamic processes in valves, tubings, and nozzles of the injection system, and then by diffusion.[9] To use rationally Xe, the regime of its injection should be point–like. When studying the vertical profile of the physical parameter distribution it is reasonable to use the spatial scale equal to ~ 1 km. In the case of horizontal profiles the scale should be essentially lager. If aboard the rocket there are 10^{26} Xe atoms (40 litres at 250 atm) then, bearing in mind the necessity to trace the layer 100 km length, up to 10^{24} Xe atoms may be injected in every point of the atmosphere. The interaction region, in accordance with the threshold conditions, will occupy the volume of 10^{10} cm^3, therewith the radiation pulse with duration ~ 0.1 s should contain $J = 10^{21}$ photons, that corresponds to the inflow of 10^7 photons into 1 cm^2 of the Earth's surface. This radiation pulse can be easily recorded by the photoelectrical photometers with spectral selection of the signal registering the spectral region near $\lambda = (540 \pm 10)$ nm. In this spectral region there are no strong lines of the natural constituents of the ionosphere, therefore the problem of separation of the glow of the layer as a whole does not exist.

The above estimates were made taking into account the fact that under conditions of the upper atmosphere the radiative decay of XeO is the fastest of the processes determining the relaxation of a given eximer molecule.

The case when the signals conditioned by the quenching of the $^1D_2$ state are observed is slightly more complex because it seems likely that it is impossible to separate this signal with the help of spectral selection. When observing the quenching signal immediately at the OI lines it will be masked by natural temporal variations of the layer intensity. It is possible that the quenching signal can be recorded using the two–channel spectrometer recording the radiation from two neighbouring regions subjected and not subjected to the action of Xe. To realize such observations, the high angular resolution of the photometer and its accurate spatial orientation (0.5′) are needed.

In conclusion it should be noted that the short–time intensity bursts at λ = 577 Å accompanies by the frequency shift of the emission line to the short–wave region were repeatedly observed earlier (see, for example, Ref. 11), but were not physically explained. In connection with the fact that the region of observation of such bursts (the Tiksi observatory) is seismically active it is believed that these bursts are the consequence of injection of the noble gases of the lithosphere origin into the atmosphere.[12,13]

The basis of this assumption is practically 100% correlation of the regions where the described phenomena were observed and seismically active zones where the earthquakes of magnitude up to 8 took place. The possible mechanism of intake of the lithosphere gases into the upper atmosphere is the wave phenomena taking place in the atmosphere and accompanying manifestations of the seismic activity.

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