G. A. Askar'yan, G. M. Batanov, I. A. Kossyĭ, and A. Yu. Kostinskiĭ. *Aftereffects of microwave discharges in the stratosphere.* In the last few years the possibility of creating a plasma mirror in the stratosphere for relaying radio and television transmissions over large distances has been under intensive investigation. There are scores of papers, reviews,[1] and monographs[2] devoted to the detailed study of this question. It has been proposed that a microwave discharge be ignited at altitudes of 30–60 km in crossed microwave beams (Fig. 1a) and that, by maintaining the discharge, conditions of strong reflection of meter-wavelength waves be created.

The authors neglected, however, the fact that a significant part of the ozone layer (see Fig. 1b and Ref. 3), which protects all life on earth from ultraviolet radiation in the range (2–3) · 10^3 Å (the so-called Hartley band), which freely passes through air but is strongly absorbed by the ozone layer, is located precisely at these altitudes. It is sufficient to say that even a small decrease in the "thickness" of the ozone

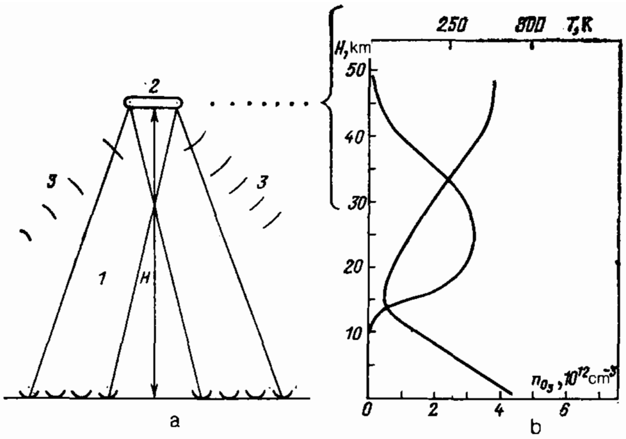

FIG. 1. Beams, plasma mirror (a), and distribution of the ozone concentration and temperature (b) (1: microwave beams, creating the plasma mirror 2; 3: relayed radiation).

layer will lead to big increases in the number of skin cancers, mutations, and other harmful biological effects.

Protection of the ozone layer is now a global problem related with increasing industrial polution, routine freon pollution, and pollution from jet engines of aircraft and rockets. Pollutants in the form of nitrogen oxides, chlorine, and fluorine catalyze the process of destroying ozone molecules, at the rate that for every molecule of the catalyst thousands to hundreds of thousands of ozone molecules are destroyed.

Our studies have shown that in prolonged microwave discharges the production of nitrogen oxides NO_x is so abundant that in the relay region a zone of strong depletion of the ozone layer should form. During the microwave discharge intense excitation of nitrogen molecules $N_2^*(v \geqslant 12)$ and dissociation of oxygen occur under the action of electron collisions, which immediately leads to formation of NO in the reactions $N_2^* + O \to NO + N$, etc.[1] Nitrogen oxide and subsequent oxides react with ozone,

$$NO + O_3 \to NO_2 + O_2, \quad NO_2 + O \to NO + O_2,$$

$$NO_2 + O_3 \to NO_3 + O_2, \quad 2NO_3 \to 2NO_2 + O_2,$$

in which the catalytic action of NO_x is immediately evident. We introduce the catalyzation factor η, which we define as the ratio of the (change in the) ozone concentration to the (change in the) concentration of nitrogen oxides, which significantly affects the ozone. For the average balance conditions the concentration is $[O_3] \approx 10^{12}$ cm^{-3}; $[NO_x] \approx 10^9$ cm^{-3} and $\eta \approx 10^3$ and for small changes $\Delta n_{O_3} \approx 10^3\, \Delta n_{NO_x}$, while for large changes $n_{O_3} \approx A / n_{NO_x}^{\alpha}$, where $\alpha \approx 1/2$.

The rate of increase in the number of oxides $\dot{N} \approx P_{av}/\varepsilon$, where P_{av} is the average liberated power in the discharge and ε is the energy "cost" for the formation of one NO_x molecule. For $P_{av} \approx$ MW and $\varepsilon \approx 10^2$ eV we obtain $\dot{N} \approx 4 \cdot 10^{26}$ molecules/h ≈ 20 kg/h, which for $\eta \approx 10^3$ and an ozone layer thickness $N_{O_3/cm^2} \approx 10^{12} \times 10^6 \approx 10^{18}$ molecules/cm^2 can create a hole in the layer with a radius $R \approx (\eta \dot{N} t / \pi N_{O_3/cm^2})^{1/2} \approx 3$ km over 1 h of the discharge. In the case of wind with a velocity u the area of the plume is $s = 2aut$ and the condition for destruction of the ozone layer is $\eta P_{av} / \varepsilon \approx 2auN_{O_3/cm^2}$, which also holds for $P_{av} \approx$ MW and $a \approx 10^2$ m even with $u \approx 10^2$ m/sec. These estimates are based on the assumption that the change in the thickness of the ozone layer is large, but in many cases (especially at low latitudes) even a small change in the thickness is inadmissible. We note that the volume of the vertical expansion of destruction of the ozone layer is maintained by convection, vortices, and vertical flows upwards and downwards, which are present in the stratosphere; with the transverse diffusion times being not less than the vertical mixing times (since the effective coefficients of diffusion are $D_\perp \ll D_{vert}$).

Experiments on the dynamics of the production of nitrogen oxides and ozone in a microwave discharge were performed in a wide range of temperatures and pressures. A microwave power flux of 200 kW per pulse with a duration of 10 μsec and repetition frequency of 2 Hz was focused into a glass chamber with quartz windows and filled with the gas under study and transilluminated with light from a mercury lamp. The production of brown NO_2 was measured based on the absorption of visible light, and the production of ozone was measured based on UV lines. The spectrum was spread out with a monochromator, and the lines were recorded by a photomultiplier. Figure 2 shows the production of NO_2 with different starting air pressures from 75 to 760 Torr. Characterisitically, because of the continuation of the reactions of NO_2 and O the production continued even after the microwave source was switched off (at 1000 sec). No traces of ozone could be seen at the level $> 10^{14}$ cm^{-3}, though ozone production was immediately noticeable in oxygen. This showed that in air, if ozone appeared at all, it was annihilated by nitrogen oxides, which were produced in large quantities: the entire cell was filled with brown gas. This production was independent of the temperature. At low temperatures (~ 120 K), much lower than in the stratosphere, ozone was detected in air after thawing. The appearance of oxides in itself can alter substantially the temperature in the strato-

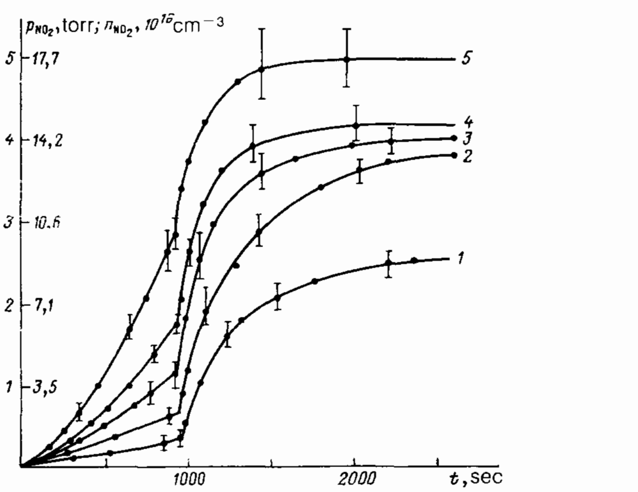

FIG. 2. Production of nitrogen oxide as a function of time for different starting air pressures (in Torr): 75 (1), 112.5 (2), 150 (3), 815 (4), and 300 (5) (the break in the curves occurs when the generator is switched off; $t \approx 10^3$ sec).

sphere and on earth owing to interception of the sunlight ("microwave winter").

We note that the harmful consequences are associated with the prolonged discharges required for prolonged relay of transmissions. In the pulsed regime (short transmissions, compressed transmissions), however, the harm from these mirrors could be significantly reduced. It is interesting to note that for single short pulses ozone production can increase. The small increase in the nitrogen oxides can bind chlorine and fluorine containing compounds into stable compounds that do not participate in the catalytic cycle.

The main conclusion is that microwave discharges in the stratosphere must be handled with great care. Prolonged powerful discharges and their propaganda should be forbidden together with airline flights in the stratosphere as well as the routine use of freon.

[1)]For high electron temperatures dissociation of nitrogen through electronic excitation of molecules followed by the reaction $N + O_2 \rightarrow NO + O$ will also be significant.

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