wavelengths gives us limits on the scale. During a total eclipse, the emission temperature of the moon's surface, as measured at infrared wavelengths, drops some 175°C during the period of less than 1¼ hours that the moon is in the earth's penumbra; but at a wavelength of 8.6 mm, as Gibson has shown (*11*), it varies less than 1°C. This evidence indicates that the sun cannot strike more than a few centimeters, at most, below the topmost elements of the skeletal structure. A lower limit to the scale is also suggested by Gibson's work (*11*); the depth to which we can see into the material probably corresponds either to his upper layer, 0.5 cm thick, or to his upper and intermediate layers, totaling several centimeters.

Thus it is inferred that the surface of the moon is probably covered by an open-textured, highly porous maze or meshwork of randomly oriented linear units with or without nodes. The structure could be a mesh or a Tinker-Toy structure, or it might resemble that of snowflakes or reindeer moss. The scale is such that one can see several millimeters or centimeters into the structure, but not several decimeters. At this scale, the average diameters of its constituent units cannot be more than a very few millimeters, and the material can appropriately be described as a skeletal fuzz.

Such a skeletal fuzz can reasonably be expected to have most of the known physical properties of the surface material of the moon. In thermal properties, it would be an excellent thermal insulator, because it consists mostly of vacuum, yet is broken up enough to reduce heat loss by radiation. It would also have a low heat capacity, because there is not much matter there to hold the heat. Moreover, it would explain the observation (*12*) that at full moon the infrared temperature of the subsolar point, at the center of the apparent disk, is higher than that of the limb. Again, the temperature of the subsolar point measured by a bolometer would vary with the phase, as it is observed to do (*13*), because it would depend on the angle at which the surface was viewed. The fuzz would also explain the observation that during the penumbral stage of a total eclipse the limb areas lose a much larger fraction of their total heat than the central regions (*14*).

Other physical properties that would be explained include the observed low electrical conductivity of the surface layer; the surface of the matter that is present is much broken up, so that path lengths would be great. Radar experts who study the moon appear to agree that a skeletal fuzz of this character would account for their observations at least as well as dust. And I believe it would account for the optical effects it was invented to explain—the lack of limb darkening on the full moon and the photometric function curves.

The remaining known physical properties of the surface material of the moon do not appear to be necessarily inherent in the skeletal structure of the inferred fuzz. For example, a fuzz could as easily be light colored as black. However, none of the known physical properties appear to be incompatible with the inferred fuzz.

The presence on the moon of a material unlike anything we know on the earth should not surprise us, because the lunar environment is so very different from our own. A possible genesis of a skeletal fuzz that would have the inferred properties is the sputtering of vesicular rocks by protons of the solar wind (*15, 16*).

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2. See H. N. Russell, *Astrophys. J.* **43**, 117 (1916).
3. M. Minnaert, in *Planets and Satellites—The Solar System*, G. P. Kuiper and B. M. Middlehurst, Eds. (Univ. of Chicago Press, Chicago, 1961), vol. 3, p. 218.
4. According to Rougier (see *5*, below), the moon at first quarter is 8.24 percent and at third quarter is 7.80 percent as bright as at full. The actual difference is even greater than this, as indicated by Minnaert (*3*).
5. G. Rougier, *Ann. Observatoire Strasbourg* **2(3)**, 205 339 (1933).
6. B. W. Hapke, *Second Preliminary Report on Experiments Relating to the Lunar Surface*, CRSR 127 (Center for Radiophysics and Space Research, Cornell Univ., Ithaca, N.Y., 1962).
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9. I use the cartographic, not the astronomic, convention for defining the cardinal points on the moon.
10. This statement is certainly true for the visible parts of the surface of the moon, although ice may be present in "cold traps" in certain craters near the poles that never receive any solar radiation and never rise above a temperature of about —200°C.
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12. E. Pettit, in *Planets and Satellites* (see *3*), p. 415.
13. F. E. Wright, "Lunar radiation," in Carnegie Institution of Washington, *Year Book 28* (1929), p. 399.
14. W. M. Sinton, in *Planets and Satellites* (see *3*), p. 439.
15. A paper setting forth this hypothesis more fully is in press (*U.S. Geol. Surv. Profess. Papers* **475-B**, art. 39).
16. This paper is published by permission of the director, U.S. Geological Survey.

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Atmospheric Iodine Abates Smog Ozone

Abstract. *Traces of iodine in test samples of irradiated photochemical smog atmospheres either inhibit ozone formation or lower its concentration. Eye and respiratory irritation are reduced qualitatively. Iodine is more effective in suppressing ozone in a photochemical smog atmosphere than it is in purified air.*

The relatively large concentrations of ozone encountered at high altitudes must be reduced when the rarefied atmosphere is compressed for use inside aircraft cabins.

As part of a study of problems that are associated with supersonic transports, we investigated catalytic methods for decomposing ozone in the air of pressurized cabins. Since ozone is also present in smog—indeed, the quantity of ozone is the usual index of smog severity—these methods seem relevant to the problem of smog abatement.

The ideal method for smog abatement is to prevent pollution of the atmosphere with its precursors, hydrocarbons and oxides of nitrogen. However, many years of effort have failed to provide practical means for reducing the nuisance. Since smog is a vital local problem, we studied the possibilities of using a trace material in the atmosphere to reduce the concentration of smog-generated ozone. Iodine proved to be unexpectedly effective in sunlight chamber studies.

The principal evaluations of the effect of iodine in smog-forming atmospheres were conducted in a portable 500-cubic-foot transparent enclosure with sunlight irradiation. One mil Mylar polyester film sheeted three walls and the top, and the frames, floor and end wall were constructed of aluminum alloy. Ozone was measured with an ultraviolet photometer in which a pair of matched photoelectric cells compares light transmission at 2537 Å through the test samples before and after the removal of ozone by catalytic decomposition with manganese dioxide.

Artificial smog, created by introducing automobile exhaust gas from an idling engine and adding nitrogen dioxide, builds up ozone on irradiation in the chamber (Fig. 1); the introduction of a weighed amount of elemental iodine, evaporated on a hot plate within the chamber, caused rapid decomposition of the ozone. Figure 1 also shows that natural smog, introduced into the chamber from the surrounding air, is affected by iodine in similar fashion. Other data (not shown) show that the quenching effect of iodine follows the same pattern for irradiated nitrogen dioxide with *n*-hexane, isooctane, and pentene-1. If the iodine is added to smog-forming mixtures in the test enclosure before irradiation, exposure to sunlight causes little or no ozone formation.

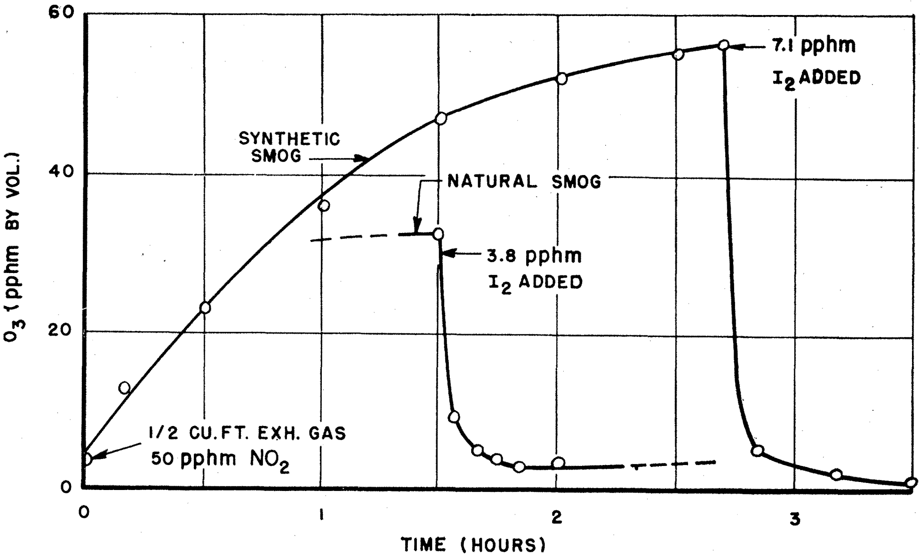

Fig. 1. Reactions between iodine and smog. Concentrations are given in parts per hundred million (pphm).

The action of iodine on eye and respiratory irritants in smog was estimated qualitatively in a preliminary manner by polluting smog-free air in the chamber with exhaust gas and nitrogen dioxide, irradiating it, and exposing observers to the irritating atmosphere before and after treatment with iodine. Six out of seven of the observers reported that the treatment effectively prevented the irritation which was associated with the control sample. The seventh observer was apparently insensitive to irritations of this type. Also, several series of eye tests indicated that the iodized atmospheres were either nonirritating, or less irritating than the controls.

In the decomposition of smog-generated ozone, the volumetric ratio of the ozone removed to the iodine added is approximately 7 to 1. The reaction is rapid; it is 90 percent complete in less than 10 minutes. Of this period, about 2 minutes was required for evaporation of the crystalline iodine, at least a minute was required for mixing, and another minute was required to obtain the analysis.

The decomposition in the dark of ozone in purified air by iodine has been found to approximate a volumetric ratio of $O_3:I_2$ of about 4.8:1, and the reaction is about 1/10 as fast as that under comparable conditions in sunlight. The decomposition in sunlight of ozone in purified air by iodine has a reaction ratio of $O_3:I_2$ approximating 5.1:1, and the rate of reaction is rapid, of the same order of magnitude as that of smog-generated ozone. The greater rate of reaction of iodine in sunlight indicates that the initial step in the reaction probably involves the dissociation of the iodine molecule, for visible light shifts the thermal $I_2 \rightleftarrows I + I$ equilibrium in favor of dissociation.

Care must be taken in irradiation studies of iodine-smog systems to assure that the photoenergy employed closely approximates true sunlight. Iodine dissociation, upon which the rate of iodine reaction in the smog system is highly dependent, occurs predominantly between 4000 and 5000 Å; the rate of smog formation predicated on the dissociation of nitrogen dioxide is influenced by that part of sunlight below 4000 Å. If artificial light sources, such as mercury lights, whose energy spectrum is disproportionately heavy in the near ultraviolet (compared with sunlight) are employed, the full effectiveness of iodine in quenching smog reactions under natural sunlight conditions may be masked.

The reason for the substantially increased effectiveness of iodine in suppressing smog-produced ozone over that in purified air has not been established, but free radicals probably play an important part in the formation and maintenance of smog-generated ozone. Quenching of free radical reactions by iodine is well known, and since the production of smog products such as aldehydes, peroxyacyl nitrates, and ozone, which are responsible for many of the adverse effects of smog, can be shown to result from free radical reactions (*1*), it is reasonable to expect that iodine would suppress the symptoms of smog. Inhibition of the photochemical reaction of olefins with nitrogen dioxide by iodine has been confirmed, and retardation of the formation of aldehydes, peroxyacetyl nitrate, and aerosol has been measured (*2*).

Another independent series of experiments with combinations of iodine, ozone, olefins, and oxides of nitrogen in a glass chamber, illuminated by mercury lamps and fluorescent tubes, has substantiated the pronounced effect of iodine on simulated smog reactions (*3*).

Our work indicates that in *sunlight*, the presence of iodine in volumetric concentrations of approximately one order of magnitude less than that of the hydrocarbon and nitrogen dioxide reactants will effectively suppress the generation or reduce the concentration of either natural or artificial smog-formed ozone.

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