Minor components such as Al_2O and CaO may be important, but their effect on the location of the phase boundaries and the seismic velocities is difficult to evaluate. A garnet content of 10 percent will decrease the velocity in the spinel portion of the mantle by 0.1 to 0.3 km/sec and by 0.2 to 0.6 in the postspinel portion of the mantle. Everything else being equal, the presence of 10 percent garnet will decrease the velocity below 700 km by about 0.2 to 0.3 km/sec more than the velocity is decreased between the two discontinuities.

The effect of garnet, or of an assemblage containing Al_2O_3 in addition to SiO_2, MgO, and FeO, on the transition pressures is not known. However, the good correspondence between the depths and thicknesses of the transition layers in the mantle with those predicted for an olivine mantle suggests that the major features of the mantle between 200 and 700 km are dominated by phase changes in the system Mg_2SiO_4–Fe_2SiO_4.

The depths to the top of the transition regions are governed both by composition and temperature. Using the phase diagram, Fig. 3, and the values of the dP/dT from Table 2 it is possible to construct curves that give the temperatures and compositions that are consistent with the observed depths of the seismic discontinuities; Fig. 6 shows the results. Taking the depths to the tops of the discontinuities as 365 and 620 km and dP/dT of the transitions as $+0.05$ kb/°C and -0.05 kb/°C, respectively, upper bounds can be put on both the fayalite content and the temperature at the top of the upper discontinuity by assuming that the temperature increases with depth. From Fig. 6 Fe_2SiO_4 is less than 35 percent and T is less than 1760°C. For a fayalite content in the transition region of 20 mole-percent and uniform, $T(365)$ equals 1520°C and $T(620)$ equals 2160°C. For a fayalite content at 620 km of 30 mole-percent, $T(620)$ equals 1880°C.

The depth distribution of earthquakes has been studied by many seismologists (*19*) but there has been no obvious correlation with known discontinuities or low-velocity zones. The maximum depth of earthquake activity is near 700 km. Gutenberg computed the average annual seismic energy release as a function of depth and found maxima centered at 350 and 600 km. There is thus some suggestion that the depth distribution of deep earthquakes in tectonic regions is influenced, if not controlled, by the location of transition regions. One possibility is that stress is most effectively concentrated in those regions where the elastic properties are changing most rapidly. Another possibility is that phase changes are still occurring in the mantle in tectonic regions and the stress field in the mantle is readjusting to these phase changes.

Recent high pressure experimental petrology studies on the olivinespinel transition in the $Mg_2SiO_4 \bullet Fe_2SiO_4$ system have made it possible to construct a theoretical mantle that is in remarkable accord with latest seismic data. Although the mantle certainly contains minerals other than olivine, the important features of the velocity variation in the transition region seem to be controlled by solid-solid phase changes in magnesium-rich olivine. There is some evidence that the fayalite content increases with depth in the transition region, although other interpretations are possible. The depths of the transition regions are consistent with temperatures near 1500°C at 365 km and 1900°C at 620 km.

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Abundance of Type II Diamonds

Abstract. *More than 1300 natural microdiamonds, mostly averaging 0.0015 carat, were studied for transparency to ultraviolet radiation, λ2537. Of most of them, of this size, 16 percent were completely transparent (presumably type II); 27 percent, completely absorbent (presumably type I). The remainder transmitted partially. The number of type-II diamonds is unexpectedly very high; a considerable proportion of microdiamonds may begin life as type II, later incorporating absorbent type-I material.*

Diamond is such a variable material that, for conclusions about general properties, large numbers must be examined. Examination of tens (*1*) or even of 100 or 200 (*2*) may at times be inadequate. In a recent investigation (*3*) of birefringence, 5000 separate diamond crystals were examined. Considerations of time and manpower obviously restrict the kinds of studies when the numbers of crystals involved run into thousands. We now report an ultraviolet-absorption investigation made on 1310 selected, optically very clear, visually perfectly transparent, natural microdiamonds.

Synthetic industrial diamonds vary from 0.2 to 1.0 mm in diameter. As some of these are under optical examination, we have set out to study the optical and microtopographical characteristics of natural diamonds of comparable size. Such small natural diamonds are not normally available, because their separation is uneconomic. Since the standard grease-table extraction process always leaves some fine tailings, we obtained from several South African mines about 1000 carats of finest-mesh tailings. The material consisted largely of chips and fragments broken from bigger pieces of diamond, yet about 1 percent comprised small, well-shaped, single crystals of diamond. By laborious sorting under the microscope we extracted from the 1000 carats about 3000 well-shaped microdiamonds—octahedra, dodecahedra, and triangular twins. From them we picked 1310 as being clear, water-white, transparent, and very largely free from inclusions. Possibly because of sorting with different mesh at the different mines, the diamonds divided themselves into two groups with regard to size: most (1030) were close to 0.8 mm across, the remaining 280 being nearer to 1.2 mm.

It has always been accepted that type-I and type-II diamonds can be differentiated by their ultraviolet transmission. We agree that the usually accepted boundary-edge limit close to λ3000 is somewhat uncertain (*1*), and that one can much more reliably differentiate the types by their response to light of wavelength λ2537 of mercury.

Measurement of individual extinction coefficients for 1310 diamonds would take too much time, especially with such small sizes. We have found that a simple procedure suffices for clear differentiation between ultraviolet transmission and absorption. A number of crystals were sprinkled over the gelatin side of a blue-sensitive fine-grain photographic plate placed on a table. From a monochromator, the plate was illuminated at normal incidence with a parallel beam of light of wavelength λ2537. Crisp, well-defined images formed (Fig. 1), capable of a fair amount of subsequent magnification and showing quite clearly whether a crystal is opaque or transparent. Magnification of the images shows that many crystals are opaque or transparent in local regions, which are often crystallographically oriented. We have established that the relatively weak fluorescence shown by many of the diamonds is much too insignificant to affect our conclusions.

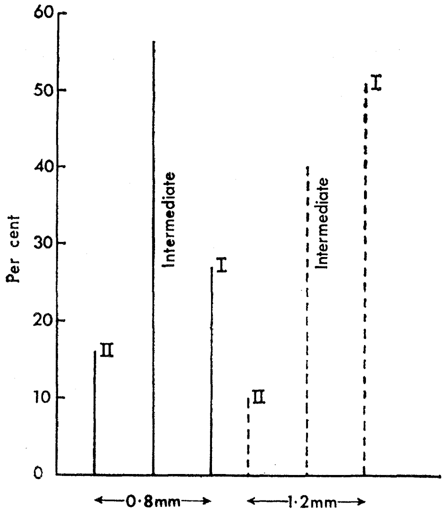

Fig. 2. Distributions of pure type-I, pure type-II, and intermediate microdiamonds as functions of size: 0.8 mm (1030 crystals) or 1.2 mm (280).

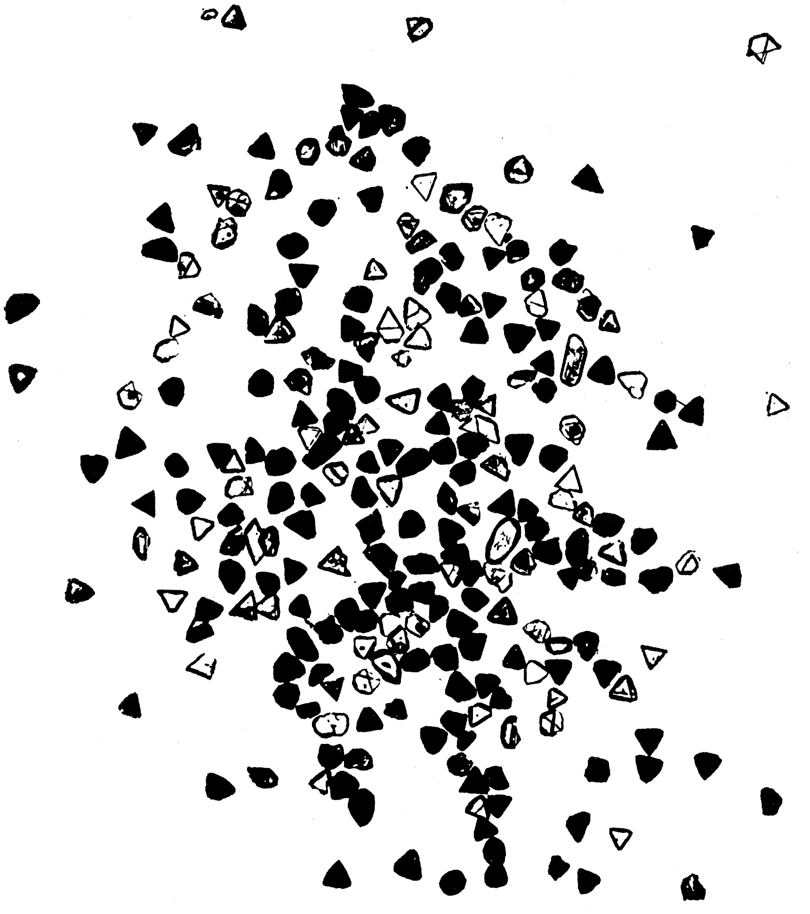

Fig. 1. Positive image of microdiamonds on a photographic plate (× 4). Forty-eight percent are judged ultraviolet-opaque (black); 52 percent, transparent.

Figure 1 (a positive) is typical: some crystals are completely opaque (black); others, completely transparent; still others, partially transparent. Yet all were quite transparent to visible light. The scatter at the edge of even the most transparent crystal leads to the appearance of a darkened outline. We are quite certain that the appearance here of ultraviolet transparency or opacity is not primarily due to difference in crystal thickness, for visually transparent crystals of the same effective thickness are variously completely transparent or completely opaque. Furthermore, when path length was doubled or trebled by heaping two or three transparent crystals on top of each other, the combination did not lead to any noticeable increase in opacity. Quite clearly, transparency or opacity is an inherent built-in property. The absorbers are very opaque, even though the crystals are only 0.8 mm thick.

The crystals divide into three groups: (i) the completely transparent—obviously type-II diamonds; (ii) the completely opaque—obviously type I; and (iii) many intermediate crystals, partially transparent but with local partially absorbent regions. Compared with the type-I diamonds with their strong opacity, these intermediates seem to be mainly of type II with an admixture of absorbent type-I material; they vary in opacity over a fair range.

Figure 2 shows the percentage distribution of pure type I, pure type II, and intermediates. Surprising is the large number of transmitters (type II). In the 0.8-mm group, 16 percent are completely transparent. Partially transparent intermediates comprise 57 percent of the total; complete absorbers, 27 percent. Handlers of diamonds know that type II occurs more often among smaller than among larger diamonds, but the true frequency of type II is known only very vaguely if at all: "maybe one in a thousand" or "possibly one in a hundred." Such guesses usually refer to crystals exceeding 0.2 carat, while our main group of diamonds averaged 0.0015 carat.

Our observations establish that in our size range about 1/6th of the diamonds are completely ultraviolet-transparent, and that about half are partially transparent—transparent in local patches. Therefore we suggest that many diamonds begin life as ultraviolet-transparent type-II crystals; as they grow, most begin to incorporate ultraviolet-absorbent regions. Since our crystals were all visually transparent and clear, it is logical to postulate that these absorbent regions are diamond of type-I character and not merely opaque foreign inclusions—witness the significant change in distribution shown by our group of large crystals.

The 16 percent completely transparent among our smaller crystals falls to 8 percent for our larger crystals. The intermediates constitute 41 percent, but the type-I diamonds (completely ultraviolet-opaque) have changed from 27 percent among the smaller crystals to 51 percent for the larger.

We do not think that this marked increase in absorption is due to a simple logarithmic increase (akin to Lambert's law) caused by increase in thickness; rather we attribute it to the probability during growth of incorporation of thin yet strongly absorbent layers. Clearly, if only a few sufficiently absorbent layers of type-I material are incorporated during growth, the whole crystal can easily become quite opaque, despite the fact that the absorbent layer may account for only a fraction of the total thickness. On this hypothesis of mixture one can predict that the number of transparent crystals will fall rapidly as their size increases, so that we soon arrive at the guess estimates—less than 1 percent—usually made for the larger crystals.

If correct, our interpretation directly opposes the usual conception regarding the scarcity of type-II diamond. We believe that during the early stages of growth this type is widespread; it may even predominate. As growth proceeds, the common incorporation of material resembling type I makes most larger crystals ultraviolet absorbent. Thus the rare large type-II crystals are those that, by some accident of growth, have avoided incorporation of type-I material.

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Evaporation of Ice in Space: Saturn's Rings

Abstract. *The photosputtering erosion velocity of ice in space is estimated to be 400 centimeters per billion years at 1 astronomical unit.*

The low reflectivity of Saturn's rings near 1.5 μ (*1*) and 1.06 μ (*2*), together with laboratory reflectance measurements of solid H_2O and CO_2 (*2*), encourage belief that the rings of Saturn consist of, or are coated with, frozen water. An optically thin piece of ice in space assumes a temperature $< 100°K$ at a distance of 1 A.U. or more (see *3*); the thermal evaporation rate at 90°K "indicates that the largest ice particle which could have evaporated since the origin of the solar system is only slightly larger than a water molecule" (see *2*).

We doubt that the evaporation rate of ice in space is limited by thermal processes: ultraviolet and solar wind sputtering should each erode orbiting ice at rates many orders of magnitude greater than will thermal evaporation. Photosputtering in the infrared may also contribute, but this rate is difficult to estimate. Visible and x-ray photosputtering are probably negligible.

For a solid for which the optical absorption length is large with respect to molecular dimensions, the surface loss velocity can be expressed as

$$V = \int_0^\infty dx \int_\lambda P(\lambda,x)\; I_\lambda(\lambda)\sigma(\lambda)d\lambda \qquad (1)$$

where I_λ is the incident photon flux per unit of wavelength, σ is the absorption cross section, and $P(\lambda,x)$ is the probability of mass ejection as a function of wavelength and depth below the surface. $P(\lambda,x)$ will be very small at depths greater than a monolayer thickness, χ. With ultraviolet absorption at wavelengths where electrons are promoted to antibonding orbitals, the molecular or ionic fragments may recoil efficiently, and $P(\lambda,\chi)$ may approach unity so that

$$V_{uv} = \chi \cdot \int_\lambda I_\lambda \sigma d\lambda \qquad (2)$$

where $\chi \sim 10^{-8}$ cm. This integral is $\sim 1.3 \times 10^{-6}$ sec^{-1}, evaluated with the absorption cross section of bulk ice (*4*) and the solar intensity function at 1 A.U. (*5*); the maximum in the integrand is at 1500 Å.

At this wavelength the ejecta should largely be H and OH free radicals. With χ equal to 1 Å, V_{uv} is 1.3×10^{-14} cm/sec or 400 cm/billion years at 1 A.U. The same integral in the IR with $\lambda < 2.35$ μ (which corresponds to the heat of sublimation of ice at 12.2 kcal/mole) is 1.5×10^{-4} sec^{-1} (*6, 7*). This integrand has maxima at 1.5 μ and 2.0 μ, which correspond to vibration bands ($2\nu_1$, $\nu_1 + \nu_3$ and $\nu_1 + \nu_2$, $\nu_2 + \nu_3$) (*6, 8*), and for which, therefore, strong recoil is not likely. In consequence $P(\lambda,\chi)$ is probably very much less than unity, and V_{IR} is probably less than V_{uv}. The visible and x-ray region should contribute negligibly, both because the integrals are small and because recoil is inefficient.

Sputtering by proton bombardment from the solar wind will also contribute to ice erosion in space. At 1 A.U. a proton flux of 2.5×10^8 cm^{-2} sec^{-1} (*9*) and an estimated sputtering efficiency of 10^{-1} (*10*) results in $V \sim 6 \times 10^{-16}$ cm/sec or 20 cm/billion years. In this case uncertainty in the solar-system magnetic field makes it difficult to estimate proton sputtering rates near Saturn ($\sim$ 10 A.U.).

These estimates, of course, say nothing about whether the rings of Saturn are ice or not, but the lifetime implications are obvious: in the absence of an accretion mechanism, a 100-μ ice mote in the sun's ultraviolet field at 10 A.U. would survive about 10^5 years. Near Saturn, accretion doubtless does occur; if sticking is efficient an ambient gas density of only 10^2 particles/cm^3 would balance the photosputtering rate. However, hydrogen atoms do not stick effi-