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

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

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

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

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 $\lambda < 2.35\ \mu$ (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 efficiently in ice at 90°K (*11*), and OH should preferentially be lost downward to the planet's surface. If Saturn's rings are ice, an adequate description of their kinetics must certainly be very complex.

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26 June 1967

Orientation of Nonsense Codons on the Genetic Map of the Lac Operon

Abstract. *Intracodon recombination is used to orient the nonsense codons UGA, UAG, and UAA on the genetic map of the (lactose) lac operon of* Escherichia coli. *The 5′-end of these triplets is toward the operator end of the operon. A hypothesis is presented to explain the fact that the frequency of recombination between adjacent nucleotides is many times lower than expected.*

Two genetic markers must be at different sites on the chromosome in order that we may observe recombination between them. The closest possible pair of markers from which recombination is to be expected are neighboring nucleotides. Recombination between adjacent nucleotides was first studied by Guest and Yanofsky (*1*) who determined the base sequence of mutant codons from the amino acid substitutions that these mutations produced in tryptophan synthetase. Recombination frequencies of the order of 10^{-3} percent were found between markers in adjacent nucleotides as compared to 4 percent for the whole tryptophan synthetase *A* gene which has a length of 280 amino acids. By measuring the frequency of unselected outside markers in these crosses, Guest and Yanofsky were able to orient several codons on the genetic map showing that the 5′-end of the "sense" strand triplet was toward the NH_2-terminal end of the protein. The sense-strand of DNA is the one with the same base sequence as mRNA (*2*). Thus, for example, if the mRNA codon is UGA, the sense-strand DNA codon will be TGA. Here we only use U and not T, and the 5′ end is always on the left.

In the case of the three nonsense codons UGA, UAG, and UAA, it is possible to determine the identity of mutant codons without any analysis of the protein involved. This is accomplished by using a series of outside suppressors that suppress nonsense mutations with sufficient specificity to determine which of the three possible nonsense triplets cause the defect. Examination of the base sequence of the three nonsense triplets indicates that recombinants should be obtained from crosses between UGA and UAG but not between UGA and UAA or between UAG and UAA when these triplets occur in the same codon. This expectation was shown to be true in crosses between a series of nonsense mutants in the same codon of the *rII* gene of T4 bacteriophage (*3*).

In crosses between UGA and UAG in the same codon, two recombinant triplets are possible, that is, UAA and UGG. The UAA is also nonsense and thus cannot generally be selected from the parental mutations. The codon for typtophan (UGG) will give an active protein only if tryptophan is an acceptable amino acid in the particular case being studied. Tryptophan will always be acceptable if the UGA and UAG mutations used in a cross are derived from the same UGG wild-type codon by single-step mutational events. A pair of UGA and UAG mutants that fit these criteria have been identified (*4*).

I now report the results of crosses between these UGA and UAG mutations in the same codon of the β-galactosidase (*Z*) gene of *E. coli.* When I used outside Z^- markers and selected for lac+ recombinants, it was possible to orient these triplets on the map of the lac operon and to show that the 5′-end of the codon is toward the operator end of the operon. No recombination was found in crosses between UGA or UAG and a UAA mutant in the same codon. This expected result serves as added confirmation that the UAG and UGA mutants studied were really in the same codon. The recombination frequency between adjacent nucleotides was measured and was found to be an order of magnitude lower than expected from the size of the *Z* gene given by data on genetic and protein structure. An hypothesis to explain this positive interference in recombination between adjacent bases follows.

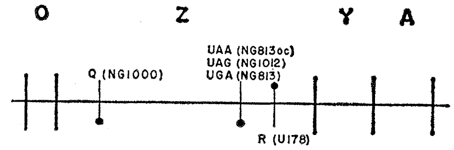

Fig. 1. Map of the lac operon of *Escherichia coli. O,* operator; *Z,* β-galactosidase; *Y,* permease; and *A,* thiogalactoside-transacetylase. The position of the markers in these experiments is roughly to scale. Since UGA, UAA, and UAG are in the same codon, they are shown to map at a single point.

Preliminary tests indicated that the recombination frequency between adjacent nucleotides was so low that recombinants could not be observed above the background of spontaneous lac+ revertants. To overcome this problem and to provide information for ordering the adjacent markers, double lac− mutants were constructed. To insure very high transfer of the lac region to the F− strains, F′ lac homozygotes were used as the male donors.

Table 1. Results of recombination between adjacent nucleotides. Q and R refer to NG1000 and U178 Z^- mutants, respectively. The UAG mutant is NG1012, the UGA is NG813, and the UAA is NG813oc. The NG813oc was derived from NG813 by the use of suppressors as described previously (*3*). The total number of recombinants refers to the number of lac+ colonies produced by a total of 3.2 ml of mating mixture on eight plates in 48 hours.

Parents		Total recombinants
F′ Male	F− Female	
	Single crossover	
Q . . . UAG	UGA . . . . R	35
	Triple crossover	
Q . . . UGA	UAG . . . . R	7
	Nonrecombinant controls	
Q . . . UAA	UAG . . . . R	1
Q . . . UAA	UGA . . . . R	2
Q . . . UGA	UGA . . . . R	1
Q . . . UAG	UAG . . . . R	4
	Nearest outside marker	
UAG	R	102,000