market. Macs and Unix systems would undoubtedly be more frequently attacked if they were dominant, although their underlying architecture and maturity might result in less (but not zero) success for attackers. It is definitely not the case that malware is a problem only because of consumers' choice of operating system (the "platform"). The truth is much more complicated and far more worrisome.

Diversity of platform is a double-edged solution in that it solves some problems neatly but creates new ones. For example, if we want some machines always running, diversity makes it very difficult for one attack to wipe out all available computers—some machines are always immune. The flipside is that diversity may actually increase the "attack surface": Although some machines are safe and secure, diversity may increase the chances that other machines are vulnerable to some other attack. Diversity is a boon for survivability but a potential risk in terms of network penetration.

There is one basic fact in security: The more functionality, the more opportunities a developer has to make a mistake. The simple truth is that modern computers are anything but simple—their increasing complexity is driven by consumers' thirst for functionality. Furthermore, computers are almost ubiquitous: For most people, the cell phones in their pockets are as much computers as are their laptops. Virulent cell-to-cell malware is not far off; researchers have already seen some limited "proof of concept" efforts. Personal digital assistants, music players, "smart" appliances, and more are all increasingly making use of available connectivity. Consumers and producers alike need to understand that more functionality means more risk. Unfortunately, no change is likely in the near term, and vendors will continue to add poorly thought-out code to their products.

Despite the best efforts of researchers, malware is not going to vanish any time soon. Computers are extremely difficult to secure, and humans are often the weakest link. For example, in one hoax users were encouraged to delete a particular file from their computers. Many users did exactly that and carefully followed the instructions to forward the warning message to all their friends. The file they deleted was critical to the system; the "virus" was executing in their minds. There is no obvious "fix" for human nature—that has not changed in many hundreds of years. Because of this, it seems likely that in another 25 years time, we will all be lifting our glasses to (or because of) malware once again.

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GEOCHEMISTRY

Strange Water in the Solar System

Analysis of a primitive meteorite offers clues about the environment in which the solar system formed.

Edward D. Young

Cosmochemists use isotope ratios to understand the stellar environment in which our solar system formed. The most pronounced and mysterious of these ratios involve the three stable isotopes of oxygen, ^{16}O, ^{17}O, and ^{18}O. Normally, ^{17}O and ^{18}O separate partially from the more abundant ^{16}O according to their relative mass differences. Variations in the $^{17}O/^{16}O$ ratio are thus about half those of $^{18}O/^{16}O$. But many rocky materials in the solar system violate this expectation, exhibiting variations in isotope ratios that are independent of mass. This is most apparent in chondrite meteorites, which are remnants of primitive rocks accreted during the earliest stages of solar system formation.

This anomalous distribution of oxygen isotopes produces a distinctive line with slope equal to 1 on a plot of $\delta^{17}O$ versus $\delta^{18}O$ (*1*) rather than a slope of ~ ½ typical of oxygen reservoirs on Earth (see the figure). The cause of this "^{16}O anomaly" has been a mystery for three decades (*2*). Water, it seems, was a key player in the origin of the ^{16}O anomaly, and on page 231 of this issue, Sakamoto *et al*. (*3*) report evidence for the original isotopic composition of water in the early solar system. From this discovery come insights into the origin of the ^{16}O isotope anomaly and clues to the nature of the stellar nursery that gave birth to the Sun (*4*).

Many mechanisms have been proposed for producing the ^{16}O anomaly in the solar system. Perhaps we have simply inherited the isotope abundances as they evolved in our Galaxy (*5*). Or possibly the isotope ratios stem from chemically induced mass-independent fractionation, analogous to what happens during ozone production in Earth's atmosphere (*6, 7*).

Researchers have recently looked to light-induced destruction of CO as the cause. About half of the total oxygen in a protoplanetary disk like the one that produced our solar system resides in CO. Another third exists in the form of H_2O with the remainder as oxides of other elements (*8, 9*). Carbon monoxide absorbs ultraviolet (UV) light emanating from stars and is dissociated to C and O. In regions of the right gas density, UV absorption cleaves $C^{16}O$, $C^{17}O$, and $C^{18}O$ molecules in proportions inverse to their relative abundances, a process referred to as "self-shielding."

Because $C^{16}O$ is the most abundant of these isotope varieties, the oxygen liberated by CO photodissociation is ^{17}O and ^{18}O rich and ^{16}O poor. Clayton (*10*) suggested that CO self-shielding at the inner annulus of the solar protoplanetary disk might be the cause of the slope = 1 line on the $\delta^{17}O$ versus $\delta^{18}O$ plot (see the figure). Yurimoto and Kuramoto (*11*) suggested that CO photodissociation and self-shielding in the molecular cloud precursor to the solar system could have caused the ^{16}O anomaly. Lyons and Young (*12*) suggested that CO photodissociation at the surfaces of the protoplanetary disk might have been the cause (see the figure).

A key prediction of the CO self-shielding models is that O liberated by CO photodestruction reacted with H to form ^{16}O-poor H_2O (*11–14*). We know that water in the early solar system was depleted in ^{16}O relative to rocks, but the extreme depletions predicted by the CO self-shielding models were not observed. Estimates of the original oxygen isotope ratios of solar system water relied on inferences from the measured oxygen isotope ratios of "secondary minerals"

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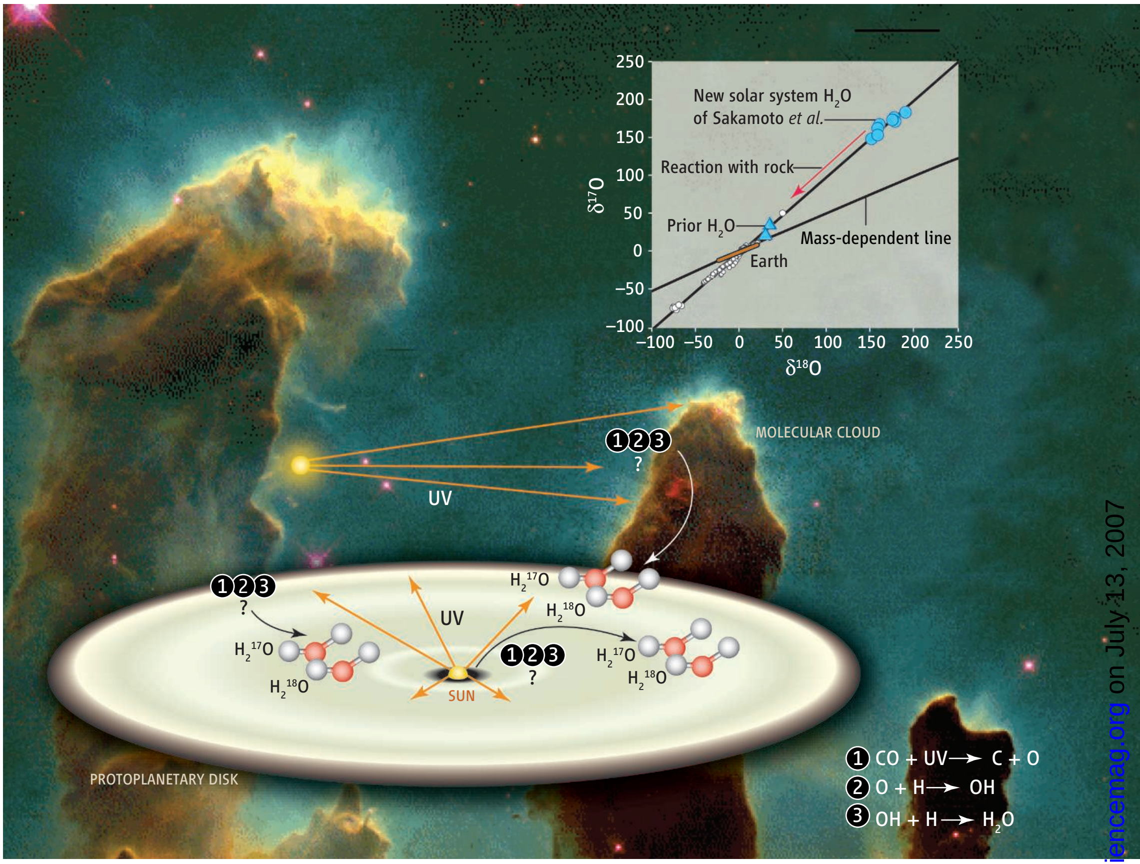
like carbonate, iron oxides, and clay minerals in chondrites (see the figure) (*15*, *16*).

These minerals grew by reactions between water and rocks in hydrologically active planetesimals, vestiges of which are found today among asteroids. Meteorite parent bodies were hydrologically active, unlike the asteroids of today, because heat from short-lived radioisotopes melted ice within the bodies, leading to the formation of carbonate, iron oxide, and clay minerals.

But there is a problem with using minerals produced by reactions between rocks and waters to infer the original oxygen isotopic composition of solar system H_2O: These secondary minerals take time to grow, whereas isotope exchange between water and rock can be rapid. As a result, new minerals generally grew from waters that had already exchanged oxygen isotopes with rock, diluting or even erasing the original isotopic composition of the water. Secondary minerals therefore generally do not have the original isotopic composition of pristine water. Instead, they inherit a mixture of rock and water isotopic compositions.



Oxygen isotope anomalies. Oxygen isotope ratios of water may record photochemical reactions in the solar protoplanetary disk. Three possible sources of ^{16}O-poor and ^{17}O- and ^{18}O-rich H_2O are produced by photochemical dissociation of CO molecules (reactions 1 to 3): (i) the inner annulus of the solar protoplanetary disk (*9*); (ii) the molecular cloud core that collapsed to form the disk (*10*); and (iii) the surfaces of the protoplanetary disk (*11*). The $\delta^{17}O$-$\delta^{18}O$ plot compares the new estimates of pristine solar system H_2O from Sakamoto *et al.* (blue circles) with previous estimates (blue triangles). Change in water isotope ratios expected as a result of reactions with rock are shown by the red arrow. Also shown are representative meteorite and lunar soil data (white circles), the slope-1 line, and the "normal" slope-½ mass-dependent line.

The discovery by Sakamoto *et al.* avoids this problem. They find hints of alteration of a primitive meteorite rock by reactions between water and rock that occurred before exchange of oxygen changed the composition of the water. In these earliest reaction products, Sakamoto *et al.* find ^{16}O depletions approaching 20%, by far the least ^{16}O seen in any solar system material to date.

Moreover, the oxygen reservoir identified by Sakamoto *et al.* lies on the extension of the line of slope 1 on the graph of $\delta^{17}O$ versus $\delta^{18}O$. This line is postulated to represent the primitive oxygen reservoir of the solar system. These extremely depleted ^{16}O oxygen abundances along the slope-1 line are consistent with the predictions of CO self-shielding models.

Sakamoto *et al.* do not prove that self-shielding was the origin of the ^{16}O anomaly. However, they appear to verify a key prediction of the models, that H_2O in the early solar system was depleted by tens of percent in ^{16}O. If CO self-shielding were verified as the origin of ^{16}O anomalies, it would show that UV light was important in the chemistry of the early solar system. The UV source could have been nearby giant stars or the Sun itself. The UV flux responsible for the ^{16}O anomaly might then indicate whether the Sun formed in a cluster of young stars or in relative isolation.

The next step will be to search for signs of CO self-shielding going on today in other protoplanetary disks. One observation suggests $C^{16}O$ overabundance (implying ^{16}O depletion): Brittain *et al.* (*17*) presented infrared spectra of the disk surrounding the young star HL Tau that imply a $C^{16}O$ enrichment of several tens of percent. Ultimately, observations on scales ranging from the width of a human hair in meteorites to protoplanetary disks many millions of kilometers away will be required to settle the origin of the solar system ^{16}O anomaly.

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