

Physics

Oxygen drips upwards from superconductors

In a famous experiment, a magnet is levitated above a superconductor that has been cooled to 77 K in liquid nitrogen. Here we show that in this set-up, liquid oxygen drops form on the superconductor, drip upwards, hit the magnet and then boil.

In this arrangement, oxygen (which boils at 92 K) condenses out of the air into the liquid nitrogen. Liquid oxygen is sufficiently paramagnetic that it can be pulled into the high-field region between the magnet and the superconductor to form a bridge (Fig. 1).

When a strong neodymium–iron–boron magnet is levitated above a $\text{YBa}_2\text{Cu}_3\text{O}_7$ superconductor, the bulk and surface-screening supercurrents provide both buoyancy and a restoring force on the magnet. The bulk supercurrents are produced by the penetration of the magnetic field into the superconductor in the form of quantized flux lines that are pinned by defects and impurities in the material.

Large drops of liquid oxygen can bridge the gap between the magnet and the superconductor. Small drops can instigate a continuous process in which a new drop begins to form on the superconductor after an old one has been pulled across the gap onto the magnet and boiled away.

An advantageous feature of this demonstration is that it does not require the handling of liquid oxygen. For further details and a demonstration of the superconductivity, magnetism and thermodynamics in action, see <http://www.dur.ac.uk/d.p.hampshire/drop.html>.

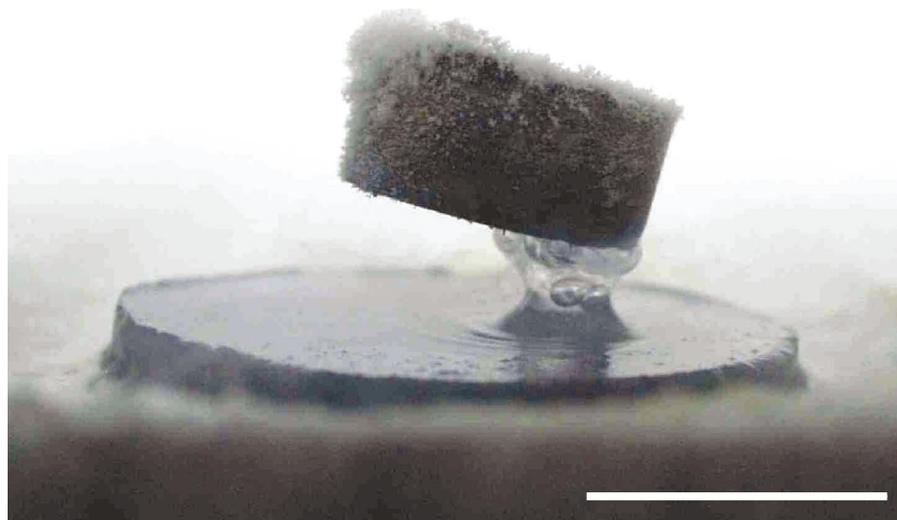


Figure 1 A bridge of liquid oxygen between a levitating neodymium–iron–boron magnet and a $\text{YBa}_2\text{Cu}_3\text{O}_7$ superconductor. The oxygen drop develops on the surface of the superconductor, drips upwards and boils on the magnet; as the old drop boils, a new drop forms on the superconductor. Scale bar, 10 mm.

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Solar System

Self-shielding in the solar nebula

Variations in the abundance of isotopes of elements in primitive meteorites carry the record of chemical and nuclear processes that occurred during the formation of the Solar System. Here I explore the possibility that photochemical self-shielding of carbon monoxide, a process that is known to occur in molecular clouds, may also have been important in the solar nebula. In the solar nebula, the process is based on far-ultraviolet radiation from the growing Sun, which is effective over a small distance in the inner part of the nebula. In order to acquire their observed isotope compositions, all of the solid matter in the present inner Solar System must have been processed through this region, and subsequently expelled to greater distances by an X-wind or similar mechanism¹.

Self-shielding in the ultraviolet photodissociation of CO is thought to be responsible for large isotopic fractionation effects that are apparent in carbon and oxygen in molecular clouds^{2,3}. Dissociation of CO, in the wavelength range 91–110 nm, occurs almost entirely by a predissociation mechanism, in which a transition occurs to an excited state with a sufficiently long life to exhibit vibrational and rotational structure, and hence to show narrow, isotopically separated absorption bands.

For example, the absorption bands around 105.2 nm are separated by 45 cm^{-1} for ^{12}CO and ^{13}CO (ref. 3), which is a large separation compared with the Doppler width. Thus, when a cloud is irradiated by an ultraviolet continuum, the wavelength that corresponds to ^{12}CO is more rapidly attenuated than that which corresponds to the less abundant ^{13}CO . As a consequence, the interior of the cloud continues to undergo photodissociation of ^{13}CO , but not of ^{12}CO . This results in an increase in the ^{13}C atoms/ ^{12}C atoms ratio of the dissociation products in the cloud interior. Millimetre-wavelength observations reveal the complementary enhancement of $^{12}\text{CO}/^{13}\text{CO}$ in the cloud interior². The same effect must occur for oxygen isotopes, and even more strongly, because of the larger isotope ratios: $^{16}\text{O}/^{18}\text{O} = 500$; $^{16}\text{O}/^{17}\text{O} = 2,500$.

The same type of isotopic self-shielding effect should occur in the T-Tauri stage of solar evolution. The proto-Sun provides a strong source of ultraviolet radiation, and it has a gas/dust disk in which the gas predominantly consists of H_2 , CO and N_2 . Irradiation of the disk produces isotopically indiscriminatory dissociation of CO at the inner edge, and preferential production of ^{17}O and ^{18}O atoms in the interior (in approximate proportion to their overall abundances). Further chemical processing within the disk, to produce solid and/or liquid condensates, should preferentially involve the heavy-isotope-enriched, reactive atoms rather than the more inert CO molecules. I have thus elucidated a process for enriching the rocky components and water vapour in ^{17}O and ^{18}O , along a slope-1 trajectory in the three-isotope graph.

During the Sun's T-Tauri stage, material that accretes along magnetic field lines falls onto the protostar at high latitudes, raising the temperature locally and providing a source of intense far-ultraviolet radiation¹. This radiation illuminates the outflowing disk wind, and produces the same kind of isotopically selective photodissociation of CO as is seen in molecular clouds³. The physical scale of this effect depends on density, temperature, dust/gas ratio, and so on. Observed and computed scales for the molecular-cloud case correspond to visible optical depths of the order of 0.5–1.0 (ref. 4), which are primarily due to dust scattering.

The most striking implication of the self-shielding model is that the overall isotopic composition of oxygen in the primordial Solar System must have resembled that in the meteoritic calcium–aluminium-rich inclusions. It has long been argued that calcium–aluminium-rich inclusions are primary condensates from a hot solar nebula⁵. On the basis of radiometric ages, they are the oldest known rocks that formed in the Solar System⁶. It is therefore unsurprising that their oxygen isotopic abundances

should be the same as those in the Sun.

However, all other meteoritic and planetary materials analysed have $^{18}\text{O}/^{16}\text{O}$ and $^{17}\text{O}/^{16}\text{O}$ ratios that are several per cent greater than the calcium–aluminium-rich inclusion values⁷, implying that this matter has been enriched in the heavy isotopes (in roughly constant $^{18}\text{O}/^{17}\text{O}$ ratios) by passing through the inner part of the accretion disk. This matter could have been returned to the colder, planet-forming regions by an X-wind process, involving an outflow of matter constituting as much as several tenths of a solar mass⁸. Photochemical self-shielding by O_2 has been considered previously in the context of earlier models of the solar nebula^{8,9}.

Photochemical self-shielding may also be important in the photodissociation of N_2 , which is isoelectronic with CO. If nitrogen anomalies were caused by isotopically selective photodissociation of N_2 molecules, there must have been a chemical trap for the ^{15}N -enriched atoms; candidate traps include H_2 to form NH and more complex molecules, and metal grains to form nitrides.

A direct test of the self-shielding model is being carried out by the Genesis mission, which will return a sample of solar wind to Earth for isotope analysis.

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Atmosphere science

Clean air slots amid atmospheric pollution

Layering in the Earth's atmosphere is most commonly seen where parts of the atmosphere resist the incursion of air parcels from above and below — for example, when there is an increase in temperature with height over a particular altitude range. Pollutants tend to accumulate underneath the resulting stable layers^{1–5}, which is why visibility often increases markedly above certain altitudes. Here we describe the occurrence of an opposite effect, in which stable layers generate a layer of remarkably clean air (we refer to



Figure 1 Clean-air slot near Maputo, Mozambique, photographed on 24 August 2000.

these layers as clean-air 'slots') sandwiched between layers of polluted air.

We have observed clean-air slots in various locations around the world, but they are particularly well defined and prevalent in southern Africa during the dry season (August–September). This is because at this time in this region, stable layers are common and pollution from biomass burning is widespread.

We were readily able to identify clean-air slots from our research aircraft by looking towards the horizon as our altitude changed. Visibility was very limited in the polluted air above and below a slot, but increased suddenly and markedly upon entering the clean air. The clean-air slot thus appears momentarily as a thin, white, horizontal layer (Fig. 1).

In 26 flights over southern Africa during a period of 6 weeks, we saw 12 well defined clean-air slots. These were most commonly encountered in the morning, a fact that is probably explained by heating of the ground during the day, with a resulting increase in convective activity which causes stable layers to dissipate. During the night, as the land cools, stable layers and clean-air slots can be re-established.

All of the clean-air slots occurred within narrow regions a few hundred metres thick, where the atmosphere was stable and the air was very dry; they were generally located about 2 km above sea level. The particle concentrations contained in these slots were only about one-third of those measured in the polluted air above and below them.

In southern Africa, pollution beneath these clean-air slots is produced as a result of widespread biomass burning, and is augmented by industrial emissions. The polluted air above the slot probably derives from pollutants that have been carried up by convective activity in regions that are not dominated by stable layers. Once in this higher band, the polluted air can presumably be transported horizontally over large distances.

Stable layers are common in southern Africa during the dry season, because of the occurrence of atmospheric subsidence⁶. If the subsiding air originates high in the troposphere, it will generally be clean and dry. The subsiding air thus has both of the

principal attributes of a clean-air slot. In addition, the dryness of the air will enhance visibility, because the particles will be devoid of condensed water⁷. The stability of the layer of subsiding air to intrusions of polluted air from both below and above will cause it to retain its pristine state. The horizontal transport of layers of clean marine air may also have been responsible for some of the clean-air slots that we observed.

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COMMUNICATIONS ARISING

Climate change

Terrestrial export of organic carbon

Dissolved organic matter in the oceans represents one of the biosphere's principal stores of organic carbon. A large proportion of this matter is drained from the continents — particularly from northern peatlands, which contain 20% of the global soil carbon¹. Freeman *et al.*² have suggested that rising temperatures may enhance this transport of dissolved organic carbon (DOC) from peatlands to the oceans. We argue here that warming can affect DOC export in different ways, depending on whether it is accompanied by increased or decreased precipitation. An alteration in the rate of relocation of organic carbon from the continents to the oceans cannot therefore be predicted on the basis of temperature change alone.

The increase in DOC transport proposed by Freeman *et al.*² is based on an observed 65% increase in DOC concentrations in British lakes and streams during the 1990s, when the mean air temperature was 0.66 °C higher than during the three preceding decades (there was no reported increase in temperature during the 1990s that was concomitant with the increasing DOC), and on a positive relationship between experimentally manipulated temperatures and DOC leakage from peat soil.

However, we question whether this is sufficient evidence for a simple and direct relationship between increased temperature and increased export of DOC. Although there are broad patterns in DOC concentration in rivers between climatic zones³, the