HIGHLIGHTS FROM PHYSICSWEB

Aerogels can be semiconductors

Scientists in the US have made the first ever aerogel with semiconducting properties. Aerogels are an important class of porous materials but most of them are electrically insulating. However, by processing materials such as cadmium sulphide or zinc sulphide it is possible to make aerogels that have densities as low as 0.07 g cm^{-3} yet still retain their semiconducting properties. If the new aerogels can be prepared in thin films, they could be used in photovoltaic and sensing applications.

Controlling devices with thought

Medical researchers have shown that signals from the brain can be used to manipulate an external device. By placing a grid of electrodes directly on the surface of the brain, a technique known as electrocorticography, a US team has shown that it is possible for patients to move a cursor on a computer screen after a short period of training. The research could ultimately lead to artificial limbs that can be controlled by thought alone, and help people with severe motor disabilities.

Satellite chalks up black-hole first

Astronomers have observed material complete an orbit around a black hole for the first time. The team calculated that gas travels around the supermassive black hole at the centre of the Markarian 766 galaxy at about one-tenth of the speed of light. The astronomers used the XMM-Newton satellite to study the X-rays that are emitted when material in the accretion disk around the black hole is heated by friction.

Nanowires form atomic switch

Physicists in Japan have made a mechanical switch that could ultimately replace semiconductor switches in electronic devices. The quantized conductance atomic switch, which works at room temperature, is made of a platinum and silver-sulphide wires that are positioned about 1 nm apart. When a positive voltage is applied to the silver sulphide, a "bridge" forms between the two wires and the switch is turned "on". A negative voltage breaks the bridge and switches the device "off".

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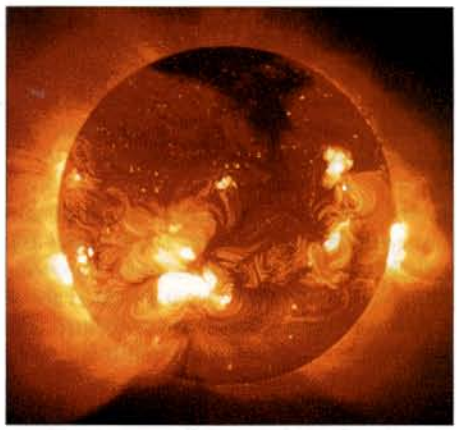
Chemical controversy at the solar surface

Improved measurements of elemental abundances suggest that something might be wrong with our model of the Sun

From **John N Bahcall** at the Institute for Advanced Study, Princeton, New Jersey, US



An accurate model of the Sun is crucial for our understanding of more-distant stars.

Solar scientists are currently re-examining everything they thought they understood about the Sun. Their aim is to locate an error in what was previously accepted lore: the standard solar model. If we cannot get the details right for the Sun – the nearest and most carefully studied star – we are probably missing something significant in our understanding of more distant stars too.

The cause of this activity is a set of improved spectroscopic measurements that indicates that the solar surface contains about 30–40% less carbon, nitrogen, oxygen, neon and argon than previously believed (arXiv.org/abs/astro-ph/0410214). The new values for the abundances of these volatile heavy elements have been determined by a team led by Martin Aspland of the Australian National University, who applied refined analysis techniques to data collected by a team of experienced observers from the US, Belgium and Sweden. But if the measurements are indeed better than previous ones, then what is the problem?

Heated debate

When the new abundances are used in detailed models of the Sun, some of the predicted solar properties conflict with observations. For example, the models predict the wrong values for the speed of sound and also the density at various locations inside the Sun, as measured using helioseismology. This highly accurate technique works in much the same way as seismology on Earth.

The problem is even more mysterious than just a discrepancy between predictions and measurements. If one uses the previously accepted values, then the predictions of the solar model are in excellent agreement with all of the quantities measured using helioseismological techniques. There almost seems to be a conspiracy at work: better is worse.

And to confuse the situation even further, the new measured abundances are in better agreement with some of the low abundances of carbon and oxygen found in the gaseous medium between stars in our neighbourhood of the galaxy. This in itself is encouraging, since the Sun presumably formed out of this interstellar medium. Indeed, before the new discrepancies between solar models and helioseismological measurements were clearly recognized, solar scientists were rejoicing that these different astronomical sites – which also include the atmospheres of some nearby stars – all gave consistent values for the carbon and oxygen abundances.

Now solar modellers – who include the present author – have shown that the discrepancies between the measurements and the solar models constructed with the new element abundances arise from a region of the Sun where the temperature is between 2 and 4.5 million degrees kelvin (*Astrophys. J.* **618** 1049). This corresponds to a region between 0.45 and 0.73 of the solar radius (see figure). We have also suggested that the most attractive explanation for the discrepancy is that calculations of the opacity of matter to light give a value that is too small by about 11% at this temperature.

Meanwhile, an international team called the Opacity Project, led by Mike Seaton of University College London and Nigel Badnell of Strathclyde University, has undertaken extensive calculations of the atomic-physics properties of the most abundant chemical elements in order to provide more accurate opacities for use in solar models and in other stellar applications. I think everyone working on this problem hoped that the new calculations would provide an increased opacity that would resolve the conflict between the solar models with the new abundances and helioseismological measurements. Unfortunately, however, the recalculated opacities turned out to be very similar to the previously accepted values.

Stellar implications

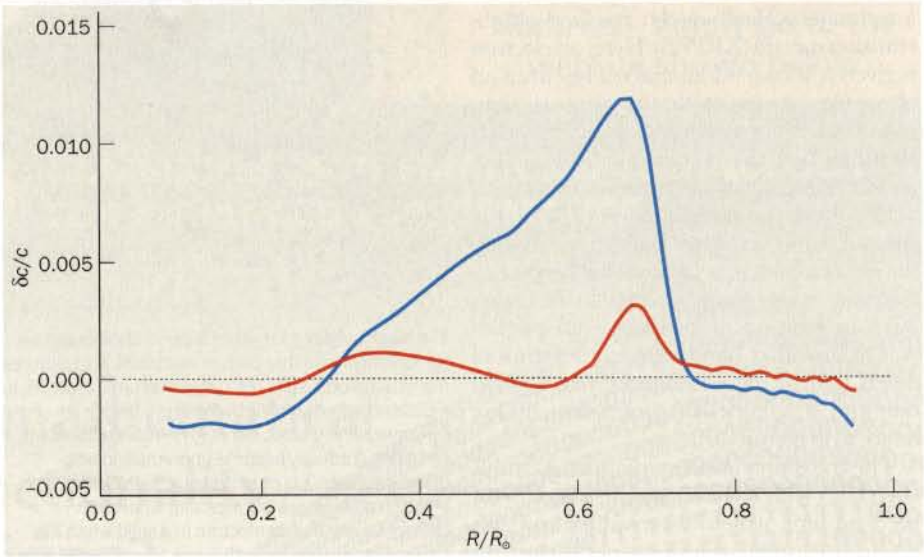
So where do we stand? We know something is wrong, we just do not know what! No-one has identified significant errors in either the theoretical calculations or in the abundance measurements, but everyone in the field recognizes that the problem is of great importance. Because of the Sun's proximity to Earth, we have much more information about it than we do about any other star in the universe. So if our theoretical model of the Sun is somehow wrong, or if the best measurements we can make of the element abundances on the Sun are wrong, then we have to be cautious in our conclusions about more distant, less well-understood stars. Almost everything we do in astronomy is based in some way or another on our understanding of stars.

Solar-neutrino physicists are among the few who can be relatively indifferent to the outcome of this particular problem, since the temperature range at which the discrepancies occur is too low to significantly affect the number of neutrinos calculated to be emitted by the Sun. But you can bet that we have not heard the last of this problem. Indeed, if previous experience is any guide, there will be an increasing number of "cocktail-hour" solutions proposed by desperate astronomers.

What next?

I think we have to systematically re-examine all the things we have previously taken for granted. For example, different groups should make their own measurements of the solar spectrum and carry out separate analyses of the chemical abundances. More specifically, the independent OPAL team at the Lawrence Livermore National Laboratory should recalculate the radiative opacity with special attention to the temperature range between 2 and 4.5 million degrees kelvin. The scientific implications of the conflict are too important to have different critical aspects of the puzzle determined by just one group, as is the case at present.

My personal guess is that it may take years before we stumble upon the key to resolving the mystery of why the improved measurements of element abundances cause solar models to disagree with helioseismological measurements while older measurements agree extraordinarily well. However, scientists love a conflict between theory and observation because they are guaranteed to learn something interesting by resolving it. We are puzzled, but we are having fun.



Solar puzzle – measurements of the speed of sound in the solar interior provide a stringent test of the solar model. This plot shows the fractional difference in the speed of sound (c) between the measured and predicted values as a function of the solar radius ($R_\odot$) (the dashed line represents perfect agreement between theory and observation). When the older heavy-element abundances are used in the model (red) the measured sound speeds agree much better with the calculations than they do when the new, lower values are used (blue).

Electrons navigate disordered media

An experiment has revealed what happens to electron wavefunctions in a metal as it melts

From **Volker Heine** at the Cavendish Laboratory, University of Cambridge, UK

Seeing is believing, even for a theorist! A beautiful new experiment has now put the seal on a problem that has been around for more than 40 years: how do waves propagate in various kinds of disordered media? In particular, how do we picture the wavefunctions of electrons in a molten metal such as aluminium or lead?

In a volume with a constant potential, devoid of any atomicity, an electron would propagate freely as a plane wave: $\exp(i\boldsymbol{kr})$, where i is the square root of -1, $\boldsymbol{k}$ is the wave vector and $\boldsymbol{r}$ is the position vector. The energy of the electron is independent of the direction of this wave, as defined by the wave vector. This means that the energy is spherically symmetric, and all electron states are filled with electrons if their wave vector lies inside the so-called Fermi sphere.

In a perfect crystalline solid, on the other hand, the electron wave undergoes multiple Bragg reflection analogous to X-ray diffraction. For example, the wavefunction of each valence electron in metallic aluminium contains constructive interference such that the electron density is "heaped" into covalent bonds between the atoms, whereas in metallic lead the electron density is heaped preferentially around the heavier atomic centres. The Fermi sphere of occupied states is then distorted and broken into anisotropic bands with energy band gaps between them, analogous to the band gaps in a semiconductor.

Two pictures

The conundrum is therefore how we should picture the electron waves in a molten metal, where both of these models would appear to have some validity. We might have a picture, A, in which the atoms scatter the electron waves much as they do in a solid, leading again to energy gaps between covalent bonding and anti-bonding states. This makes sense chemically on the very local scale between pairs of atoms, but a liquid is isotropic on any scale longer than a few atomic diameters. This suggests a second picture, B, in which electron waves propagate isotropically over such longer distances and the Fermi surface is a sphere, as it is for electrons that propagate freely.

Now Jürg Osterwalder and co-workers at the University of Zurich in Switzerland have shown very elegantly that both of these pictures apply, with one or the other dominating in different regimes (F Baumberger *et al.* 2004 *Science* **306** 2221). For their experimental medium the researchers used not bulk molten lead but an atomic monolayer of lead deposited on a copper substrate. By varying the temperature from just above the melting point of the lead monolayer (568 K) up to 670 K, they could cause the system to switch between the two pictures.

The team measured both the energy and momentum of electrons in the material using