electrostatic attraction of the charges on the particle to induced charges in the adhering surface. However, experiments have shown (*11*) that the adhesion is at least one order of magnitude larger than predicted by a model in which the charged object is represented by putting the total charge in the center of the object. Even with modifications to include nonuniform charge distributions (*11*) and nonelectrostatic forces of adhesion (*12*), these models cannot explain the observations.

Instead, the enhanced adhesion seems to be caused by the discreteness of charge, which is the way nature provides us with charge (i.e., one electron has exactly 1.6×10^{-19} Coulomb of charge) (*13*). Discrete charges near the contact points produce strong electrostatic forces approximately equal to the force of the total charge in the center of the particle. The physical picture that appears to describe the data is that there is electrostatic adhesion at every contact point (due to discrete charges). To minimize adhesion, the number of contact points needs to be minimized.

This idea has practical implications in electrophotography (*14, 15*). The number of contact points was minimized by coating the toner particles with about a monolayer of 10-nm-diameter silica nanoparticles. A toner particle with uniform small protrusions around the surface will, when placed on a flat surface, make contact only at a minimum number of protrusions, minimizing both electrostatic and van der Waals adhesion. This new toner has adhesive forces lower by a factor of at least 10 than those of commercially available toner, which has resulted in the implementation of a new electrophotographic development system. The result is a true desktop color laser printer that is presently under development, which is much smaller—about the same volume as a black-and-white laser printer—and much less expensive than is currently commercially available (*16*, *17*).

Our understanding of the charging mechanisms in insulating particles is still rudimentary, although a specific model, the electric field model, appears to have been experimentally verified. If the effective electric field could be associated with material properties of insulators, a rational approach to the design of the charging properties of insulators will be possible, changing the multibillion dollar industry of toner manufacture in electrophotography. The new understanding of charged particle adhesion has led to the design of low adhesion toner, which will dramatically change the color electrophotographic printing industry. Perhaps the concept of reducing adhesion by coating particles with a monolayer of nanometer-diameter silica will be useful in other technologies.

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ASTRONOMY

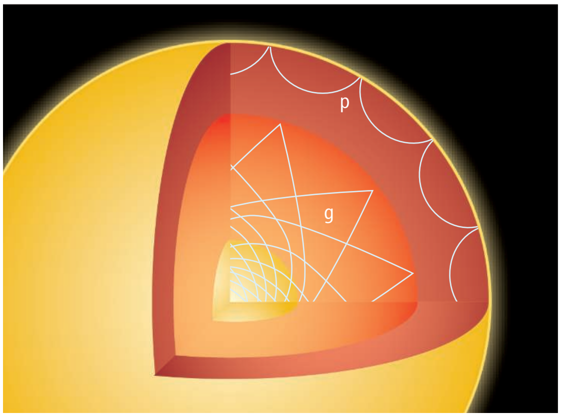
Waves in the Sun's Core

Waves deep within the Sun may help astronomers see the normally hidden core where energy-producing fusion reactions occur.

Frank Hill

Although we cannot use light waves to see inside the Sun and other stars, we can learn about their interiors from mechanical waves generated deep within. These waves, similar in some ways to seismic waves on Earth, come in two main types: gravity waves or "g modes" that are driven by buoyancy, and pressure waves or "p modes," which are ordinary sound waves. Helioseismologists seek to understand what is happening inside the Sun by observing the oscillations produced on the solar surface by these modes. Such studies have produced many solar surprises, including a bizarre pattern of internal rotation (*1*); twisting flows below sunspots that produce strong flares (*2*); and evidence that the neutrinos generated by the fusion in the core change their nature as they travel through the solar plasma (*3*). However, until now we have not been able to probe the deepest part of the Sun, where fusion reactions create the energy that sustains life on Earth. On page 1591 of this issue, García *et al*. report their work on g modes, which offers the most promising hope we have so far of examining the Sun's core (*4*).

The p modes are trapped in the Sun's outer layers, and only a very few penetrate below a fractional radius of 0.2 into the core of the Sun. The g modes, on the other hand, are trapped in the core as well as in the radiative zone, as shown in the figure. This makes them extremely valuable for reporting the temperature, pressure, and motions at the solar center. Because they are trapped so deeply, however, they produce an effect at the solar surface that is, at



Good vibrations. A cross section of the solar interior showing examples of the ray paths of different waves. Whereas the p modes are mainly confined to the outer layers, the g modes propagate near the center and can provide information about the core. García *et al.* may have observed g mode signatures in the oscillations of the Sun's surface.

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best, about three orders of magnitude smaller than what can be detected with current or foreseeable systems (*5*–*7*) such as the SOHO (Solar and Heliospheric Observatory) and SDO (Solar Dynamics Observatory) spacecraft, or the ground-based GONG (Global Oscillation Network Group) program.

Yet solar g modes do have one characteristic that makes their detection a bit more feasible: They are predicted to maintain phase coherence for years. Phase coherence means that all the waves stay in sync, so that many waves could work together to produce a distinct and useful signal. This possibility motivated García *et al*. to study a 10-year sequence of observations now available from the GOLF (Global Oscillation at Low Frequency) instrument on SOHO.

García *et al*. also exploited another characteristic of g modes: Their periods are evenly spaced, unlike p modes, which have evenly spaced frequencies. By building a model that explored the range of likely periods, along with the possible effects of rotation on the g modes, García *et al*. were able to identify a structure in the period spectrum of the GOLF data. The characteristics of this observed structure are strikingly similar to the theoretical spectrum that they constructed, making this the best indication yet that the g modes do indeed exist and are not cousins of Lewis Carroll's precisely described and long-sought but mythical snark.

In addition to adding weight to the evidence for the existence of solar g modes, García *et al*. also provide a rough estimate of the rotation rate of the core. This question has been debated for at least two decades in the helioseismology community, and there are a few bottles of vintage wine waiting to be awarded to the winner of some friendly bets on whether the core rotates faster or slower than the surface. García *et al.* are squarely in the "faster than surface" camp with these results. However, a more accurate answer must await computation of joint inversions of both the p-mode and g-mode frequencies into values of rotation rate.

Even though this is an exciting result for helioseismology, stellar structure, and solar physics, a crucial step remains before it can be truly accepted. As in all of science, confirmation is vitally important and especially so when the phenomenon has been sought for a long time, as the g modes have been. It is essential that the same analysis be performed on other data sets, and that an independent analysis be devised that can reveal the same feature in the original data set. Helioseismology is a subtle business, and several helioseismic results that would have been very exciting if true have fallen by the wayside when they could not be confirmed. However, confirmation requires the existence of an independent data set, and this may not be the case in the near future for helioseismology.

There are only two major imaging helioseismology systems in the world—the GONG program and the SOHO spacecraft. SOHO is reaching the end of its lifetime and will be replaced by the SDO mission, which is scheduled for launch in 2008. However, the Astronomy Division of the National Science Foundation, which funds the GONG program, recently conducted a high-level review to identify funds for operating future facilities. One of the recommendations of this review (*8*) is to close GONG 1 year after the successful launch of SDO, unless outside funds for GONG operations can be identified. If this happens, helioseismology will be unable to confirm its most exciting results and may die completely as a science, which would be a pity.

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IMMUNOLOGY

The Shape of Things to Come

Mechanistic understanding of how ligands can fine-tune the immune response may lead to better vaccine adjuvants.

Katherine A. Fitzgerald and Douglas T. Golenbock

A successful vaccine is usually a combination of two agents. One is an antigen, the foreign substance that triggers an immune response—namely, the production of antibodies that recognize the antigen and lead to the destruction of pathogens that bear it. The other component is an adjuvant, which boosts this immune response by enhancing the activation of immune cells (T cells and antibody-producing B cells). Adjuvants that hold considerable promise in vaccine development are ligands for certain members of the Toll-like receptor (TLR) family that are expressed on the surface of immune cells. But to harness these ligands therapeutically, a detailed mechanistic understanding of their adjuvant effects is needed. Two reports in this issue, by Mata-Haro *et al.* on page 1628 (*1*) and by Ohto *et al.* on page 1632 (*2*), provide new insights into the manner by which Toll-like receptor 4 (TLR4) becomes activated by adjuvants, and reveal molecular mechanisms by which recognition of different ligands by the same receptor shapes the immune response in different ways.

Among the ligands that activate TLRs are deoxycytidylate-phosphate-deoxyguanylate (CpG) DNA, which activates TLR9, and monophosphoryl lipid A, derived from the active moiety (lipid A) of bacterial endotoxin (lipopolysaccharide), which activates TLR4. Recognition of lipid A and related molecules by TLR4 requires MD-2. MD-2 lacks a transmembrane domain and binds to the extracellular domain of TLR4 (*3*). Activating the TLR4–MD-2 receptor complex is thought to involve reorganization of the cytoplasmic Toll–interleukin-1 receptor (TIR) domain of TLR4, enabling the recruitment of four adapter molecules: MyD88, Mal (also called TIRAP), TRIF (also called TICAM1), and TRAM (also called TICAM2) (*4*). These adapters, in turn, initiate signal transduction pathways that lead to the production and secretion of molecules that regulate immune cells, called cytokines, as well as increased expression of molecules on the surface of specialized immune cells (dendritic cells) that enhance T cell activation.

Ohto *et al*. report the crystal structure of MD-2, both in its native state and bound to lipid IVa. Lipid IVa is similar in structure to lipid A but inhibits bacterial lipopolysaccharide. Lipid IVa also lacks two of the six fatty

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