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Bridging the Atmospheric Divide
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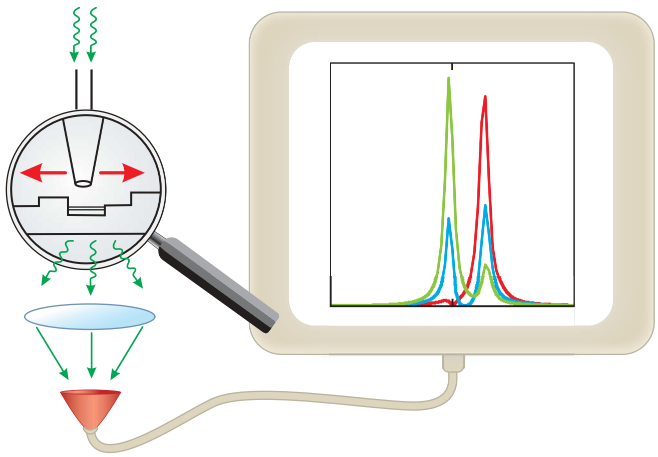
(*5*). Optical transitions between electronic states in a quantum dot are much harder to map and address with current techniques. Optical addressing of individual electronic quantum states localized on a quantum dot is a particularly challenging task.

To excite a single electronic quantum state, the light source must overlap in space with this state. However, spatial overlap is not sufficient because several states often coexist in a given structure. The incident light must therefore also overlap spectrally with the quantum state. Fortunately, these states are different in energy and can therefore be excited selectively by changing the frequency of the incident light—but only if the spatial resolution is high enough to resolve single quantum dots and the spectral resolution is sufficient to resolve the line width of a single optical transition.

Guest *et al.* have now succeeded in exciting and detecting single optical transitions on a nanometer scale in a solid material. In their experiment, spectrally and spatially well-resolved laser pulses are used to generate electronic excitations in quantum dots defined by thickness fluctuations of a GaAs semiconductor film. The nanometer-scale light source is obtained by the propagation of conventional laser light through an aluminum-coated fiber tip.

The measurements yield the dipole strength, decay times of the emission, and lifetimes of the electronic excitation as the probe is scanned over the film. These results are obtained using the nonlinear interaction of two incident light waves in the semiconductor. The nonlinear optical response leads to wave mixing between the incident waves, which can be detected in the frequency domain. The experiment combines subwavelength spatial resolution with an energy resolution in the nano-electron volt range, enabling single electronic states in the quantum dot to be addressed. By detecting the light behind the sample (see the figure), the authors show that single quantum states localized on a nanometer scale and their optical properties can be detected over an array of several micrometers.



Optical near-field spectroscopy. The light of one or more light sources (lasers) is coupled into an optical fiber with a tapered, metal-coated tip. The evanescent field of the fiber tip acts as local excitation source that is scanned over the structure under investigation (magnified in the figure). The transmitted light is collected and processed to yield optical spectra. The spectral information depends on the exact position of the excitation source (different curves on the display) and on the frequency of the laser sources.

When light excites an optical transition, the material excitation has the same phase and angular momentum as the light source. This quantum coherence decays, sometimes very fast, due to interactions with other excitations and vibrations in the material. Guest *et al.*'s technique enables them to map dynamical information associated with the excitation decay of single quantum dots and to determine the decay of optical polarization (dephasing) due to loss of quantum coherence. The work also points the way to the next inevitable advance: the development of nonlocal spectroscopy, which may be based on two NSOM probes and should enable the detection and characterization, for example, of transport of quantum coherence.

Optical techniques such as that reported by Guest *et al.* will allow us to resolve spatial properties on small scales, complementing the progress achieved by ultrafast-pulse optics in the time domain. These high temporal and spatial resolution techniques will facilitate the investigation of quantum mechanical questions concerning excitations in a complex solid state environment such as a quantum dot immersed in a semiconductor film. This work will not be restricted to pure research but may even lead to the development of a wide range of practical diagnostic tools and device applications.

References and Notes

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PERSPECTIVES: ATMOSPHERIC SCIENCE

Bridging the Atmospheric Divide

Martin J. Jarvis

One of the least explored regions of Earth's atmosphere is finally emerging from obscurity. The mesosphere and lower thermosphere (MLT), between 50 and 150 km altitude (see the first figure), has long suffered from its inaccessibility to the highest research balloons and the lowest orbiting satellites. Several international initiatives now aim to plug this knowledge gap.

The new initiatives take advantage of recent technological developments to study the MLT from the ground and from space. They are particularly timely because of the growing realization that the MLT is an important link in the vertical transfer of energy and material in the atmosphere, that mesospheric phenomena may be the most sensitive indicator of global temperature change, and that this region is becoming increasingly relevant to aerospace technology (*1*).

In summer, the polar mesopause, which defines the boundary between the mesosphere and the thermosphere, is the coldest place anywhere in Earth's atmosphere. At 130 K, it is some 70 K colder than would be expected under simple radiative equilibrium. The cooling is driven by gravity waves, which can be caused by the impact of weather on mountain ranges or by shear in the atmosphere. Gravity waves propagate upward from the troposphere and break in the mesosphere.

A slightly warmer summer mesopause is expected in the Antarctic than in the Arctic because the different land-ocean configuration in the Antarctic leads to a weaker

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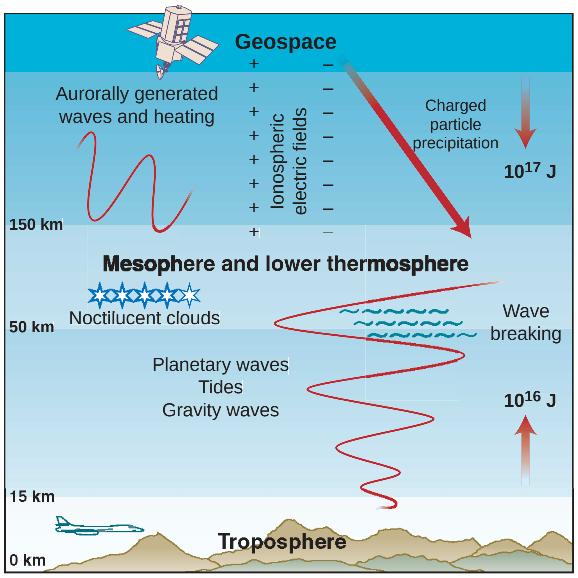
overall gravity wave field. Satellite data tend to confirm this: In midsummer, the Antarctic mesosphere is about 12 K warmer than the Arctic mesosphere (*2*). But in 1998, in situ measurements with rockets provided a surprising and contradictory result: The Antarctic summer mesopause was just as cold as that in the Arctic (*3*).

Increasing greenhouse gas concentrations warm the atmosphere at Earth's surface but are expected to cool the upper atmosphere because of increased radiative emission out into space. The cold summer mesosphere is of particular interest in this respect because its summer temperature is stable within 20 K, whereas the predicted cooling under a doubled greenhouse scenario is 10 K (*4*). It may thus provide the best signal-to-noise ratio anywhere in the atmosphere for detecting global temperature changes. Ground-based evidence that the frequency of occurrence of silvery-blue noctilucent clouds (see the second figure), formed by ice particles at ~83 km, has doubled over the past 30 years (*5*) may indicate a mesospheric cooling trend. But again, there is contradictory evidence: Temperature profiles from rockets in the Arctic show no long-term trend in mesospheric temperatures (*6*).



Energy transfer in the mesosphere and lower thermosphere. About 10^{16} J of energy propagates up daily from the atmosphere below in the form of waves and tides. During a geomagnetic storm (which occurs about every 5 days), about 10^{17} J is injected per day from space through auroral processes.

These contradictions demonstrate how little we know about the MLT. The vertical links between geospace (which extends from the ionosphere out to the Sun) and the lower atmosphere are also only just beginning to be explored. Recent studies show that the energy of planetary-scale atmospheric waves in the stratosphere can depend on the lower thermosphere (*7*), that the chemistry of the stratosphere can be affected by charged particle precipitation from geospace (*8*), and that the MLT plays an important role in the upward propagation of wave energy to the thermosphere (*9*) (see the first figure).

Noctilucent clouds over Finland.

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Recent improvements in the sensitivity of optoelectronic devices are enabling remote measurements of energy transfer in the MLT through its extremely faint airglow (the light emitted by photochemical processes in the upper atmosphere). As gravity waves pass through different airglow layers (such as the O_2 band at ~94 km), they cause variations in the emission intensities of the layers. Images of these intensity variations allow us to observe gravity wave dynamics (*10*) and calculate the momentum they transfer to horizontal winds (*11*). Spectrometry can be used to determine layer temperatures. Continuous daylight in high-latitude summer prohibits the use of these techniques from the ground, but a novel lidar with two spectrally separated iron lasers has recently taken the first summer mesospheric temperature profiles directly over the North and South Poles (*12*).

Medium-frequency and meteor radars operate continuously, independent of light conditions. The Planetary Scale Mesopause Observing System combines the output from a worldwide network of these radars and has just provided the first global data analysis of diurnal and semidiurnal tides in the mesosphere (*13*). The results show that even these most basic atmospheric phenomena do not always conform to current models.

There will soon be unprecedented focus on the MLT from satellites. The Swedish-based multinational satellite project Odin (*14*), launched in February 2001, aims to study the apparent relationship between noctilucent cloud occurrence and atmospheric CO_2 concentrations. And the NASA Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) mission, scheduled for launch in December 2001, plans to perform the first comprehensive global study of the MLT's basic structure, energy budget, and space weather and to provide baseline measurements for human-induced change (*15*).

Meteorologists have traditionally produced global circulation models that incorporate the troposphere and stratosphere (see the figure), whereas space physicists have produced global models incorporating the magnetosphere, ionosphere, and thermosphere (from ~100 to ~500 km). An ambitious modeling initiative, the Whole Atmosphere Community Climate Model, is under way at the National Center for Atmospheric Research in Boulder to bridge the gap and simulate the physics and chemistry of the atmosphere from the ground to 500 km (*16*).

The combined research front presented by these ground-based, satellite, rocket, and modeling efforts should greatly enhance our understanding of the MLT. They will provide the vital missing link to viewing our planetary atmosphere as a fully integrated system.

References and Notes

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